US012196223B2

(12) **United States Patent**
Japikse

(10) **Patent No.: US 12,196,223 B2**
(45) **Date of Patent: *Jan. 14, 2025**

(54) **BIASED PASSAGES FOR TURBOMACHINERY**

(71) Applicant: **Concepts NREC, LLC**, White River Junction, VT (US)

(72) Inventor: **David Japikse**, Woolwich, ME (US)

(73) Assignee: **Concepts NREC, LLC**, White River Junction, VT (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **18/390,777**

(22) Filed: **Dec. 20, 2023**

(65) **Prior Publication Data**

US 2024/0125331 A1 Apr. 18, 2024

Related U.S. Application Data

(63) Continuation of application No. 16/948,318, filed on Sep. 14, 2020, now Pat. No. 11,852,165, which is a (Continued)

(51) **Int. Cl.**
F04D 29/44 (2006.01)
F02C 6/12 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***F04D 29/444*** (2013.01); ***F02C 6/12*** (2013.01); ***F04D 17/10*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC F04D 29/44; F04D 29/442; F04D 29/444; F04D 29/447; F04D 29/448; F04D 29/462
See application file for complete search history.

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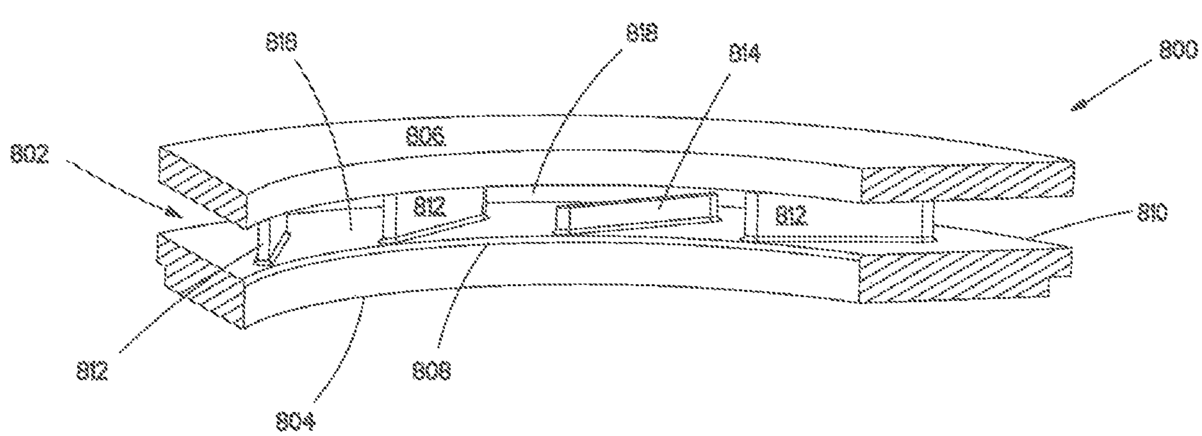
Primary Examiner — Christopher R Legendre
(74) *Attorney, Agent, or Firm* — Downs Rachlin Martin PLLC

(57) **ABSTRACT**

Turbomachines having one or more flow guiding features designed to increase the performance of the turbomachine. In some examples, flow guiding features are designed and configured to bias a circumferential pressure distribution at a diffuser inlet toward circumferential uniformity, otherwise account for such low-frequency spatial pressure variations, increase the controllability of spatial flow field variations, or modifying flow field variations, etc. In some examples, a diffuser having a row of vanes that include a plurality of first vanes and at least one second vane having a different characteristic than the first vanes are disclosed. In some examples, diffusers having an aperiodic section including one or more biased passages for biasing a flow field are disclosed. And in some examples, turbomachines having flowwise elongate recesses in one or both of a hub and shroud surface are disclosed.

19 Claims, 43 Drawing Sheets



Related U.S. Application Data

continuation of application No. 15/103,252, filed as application No. PCT/US2016/030184 on Apr. 29, 2016, now Pat. No. 10,774,842.

(60) Provisional application No. 62/243,415, filed on Oct. 19, 2015, provisional application No. 62/155,341, filed on Apr. 30, 2015.

(51) **Int. Cl.**
F04D 17/10 (2006.01)
F04D 29/42 (2006.01)
F04D 29/46 (2006.01)

(52) **U.S. Cl.**
CPC ***F04D 29/4206*** (2013.01); ***F04D 29/462*** (2013.01); *F05D 2250/52* (2013.01); *F05D 2260/961* (2013.01)

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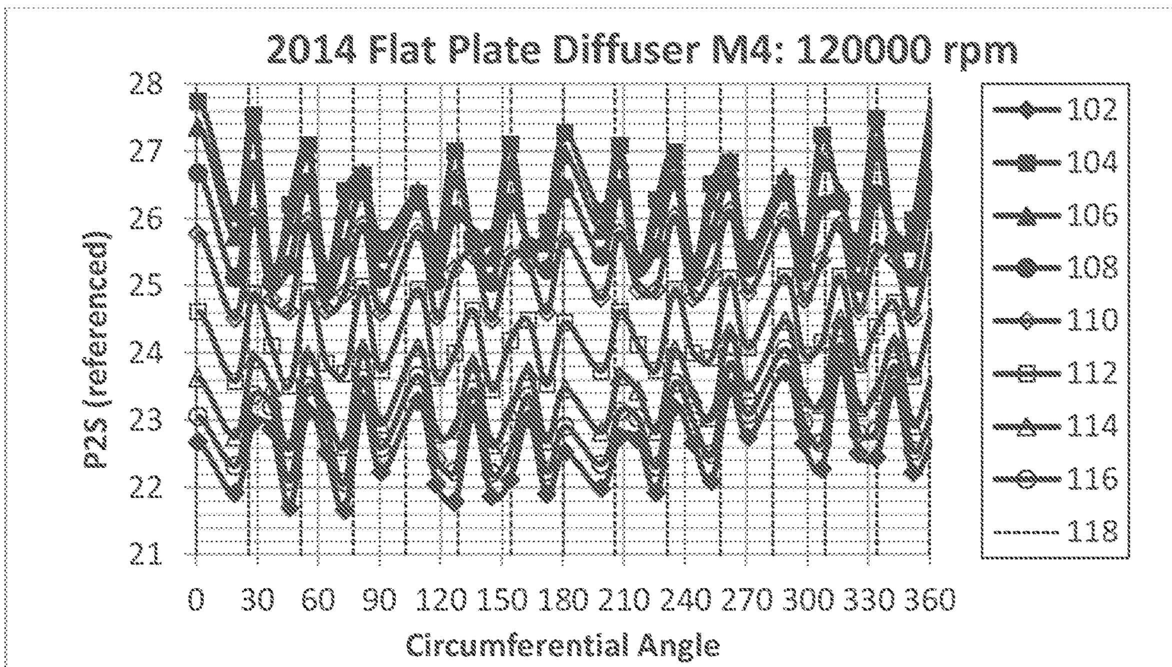
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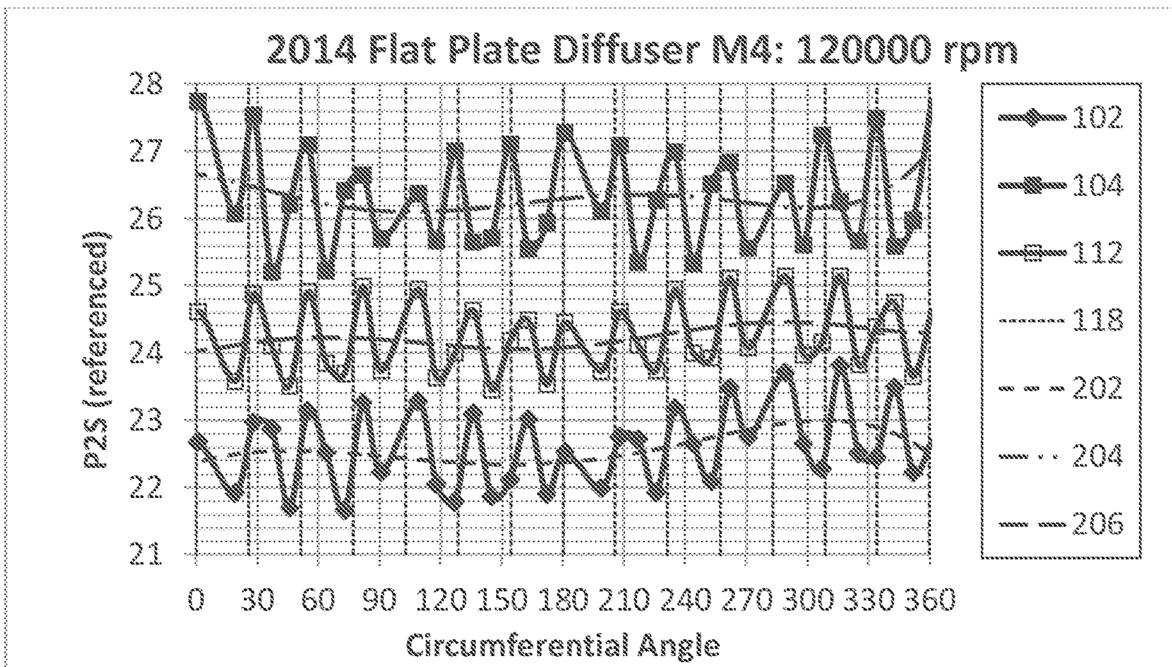
28
27
26
25
24
23
22
21
0
30
60
90
120
150
180
210
240
270
300
330
360
Circumferential Angle
102
104
106
108
110
112
114
116
118

FIG. 1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28
27
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23
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21
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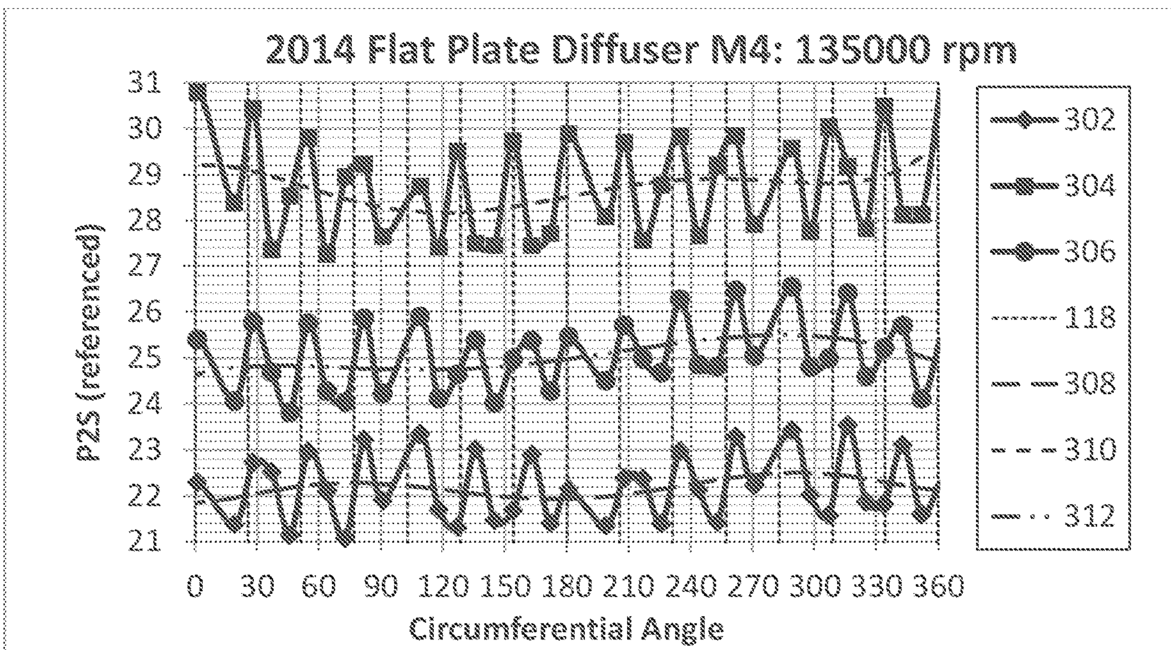
Circumferential Angle
102
104
112
118
202
204
206

FIG. 2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P2S (referenced)
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30
29
28
27
26
25
24
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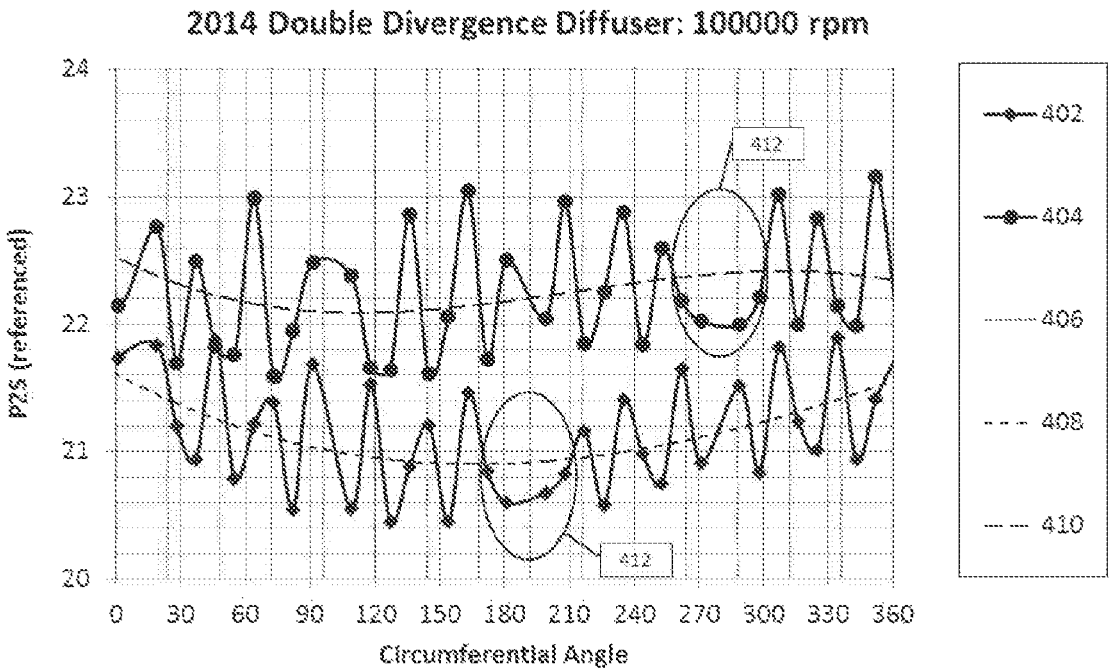
21
0 30 60 90 120 150 180 210 240 270 300 330 360
Circumferential Angle
302
304
306
118
308
310
312

FIG. 3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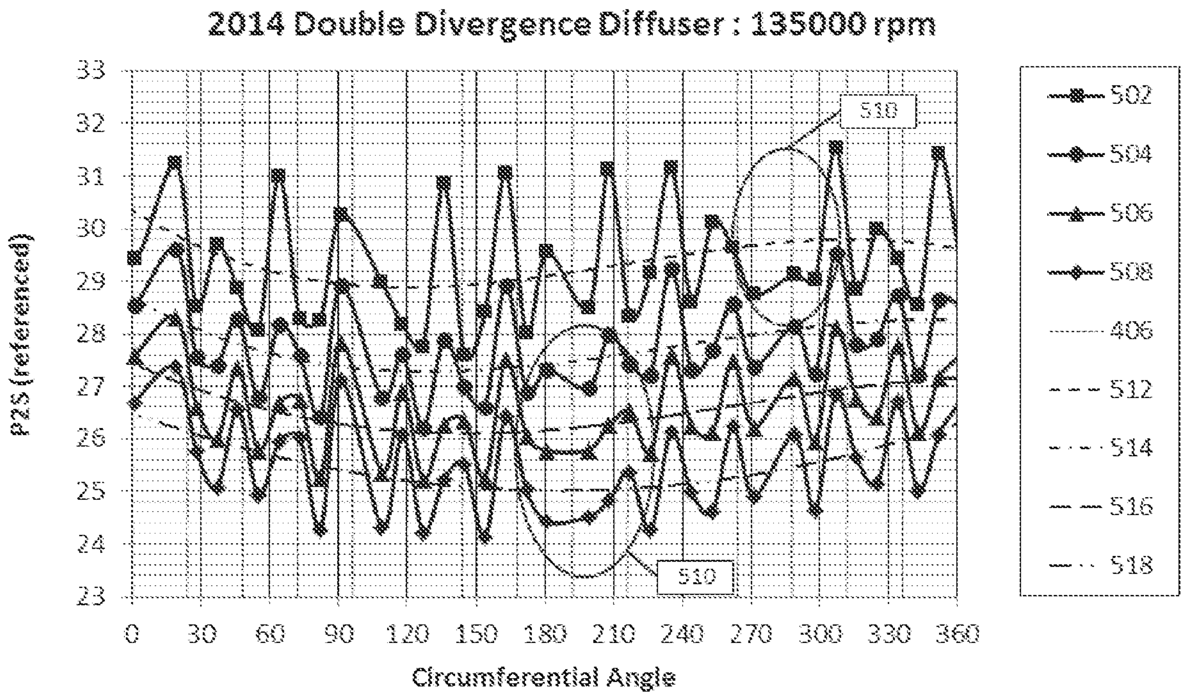
23
22
21
20
P2S (referenced)
0
30
60
90
120
150
180
210
240
270
300
330
360
Circumferential Angle
412
412
402
404
406
408
410

FIG. 4


2014 Double Divergence Diffuser : 135000 rpm
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32
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28
27
26
25
24
23
P2S (referenced)
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30
60
90
120
150
180
210
240
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Circumferential Angle
510
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502
504
506
508
406
512
514
516
518

FIG. 5

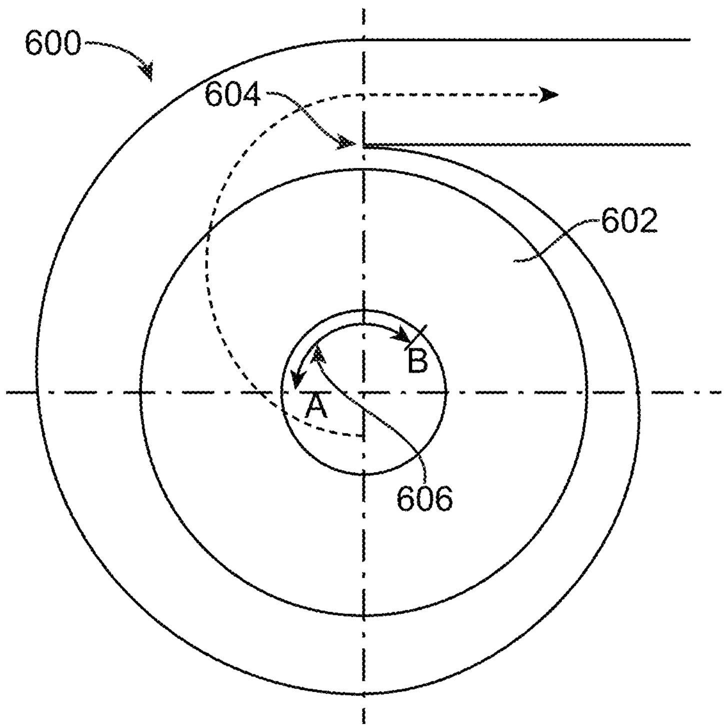

FIG. 6
(PRIOR ART)

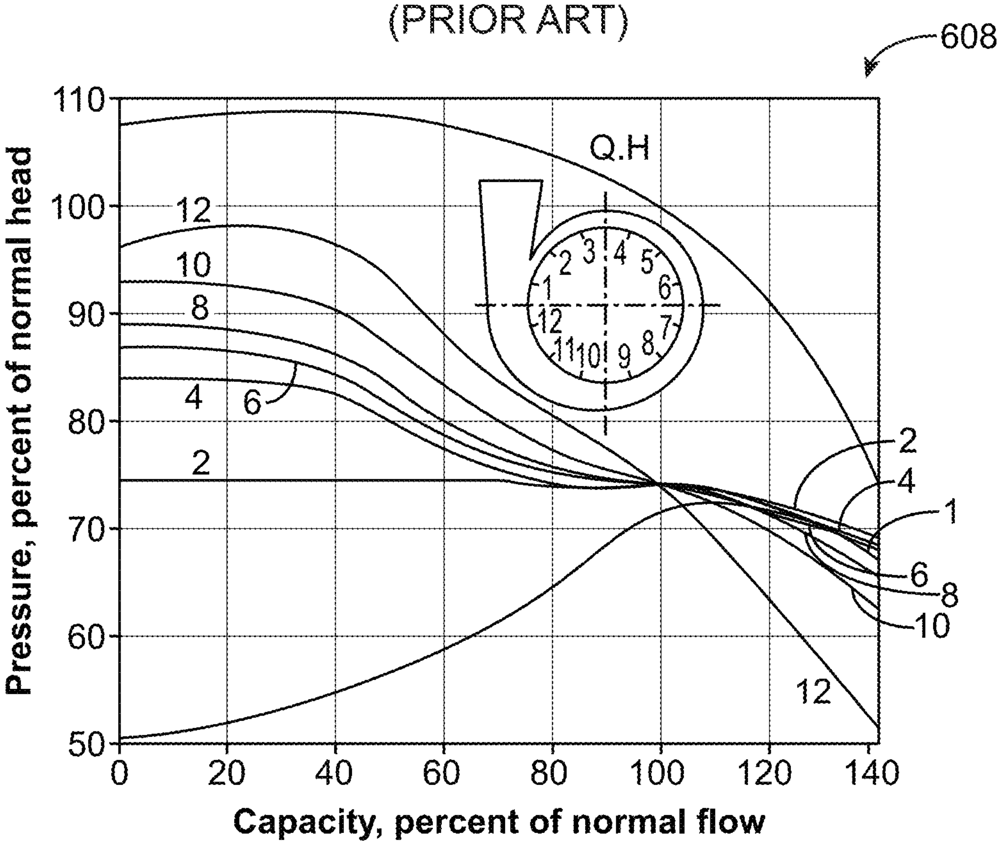

FIG. 7
(PRIOR ART)

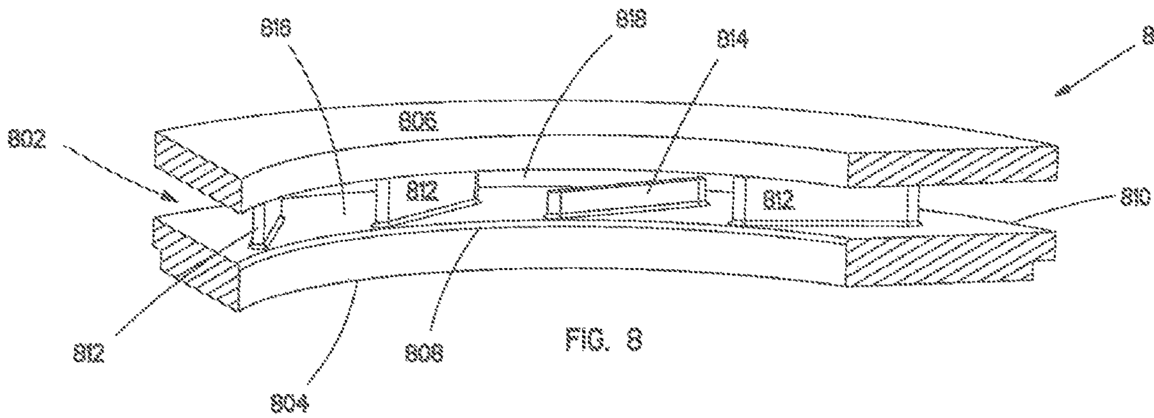
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FIG. 8

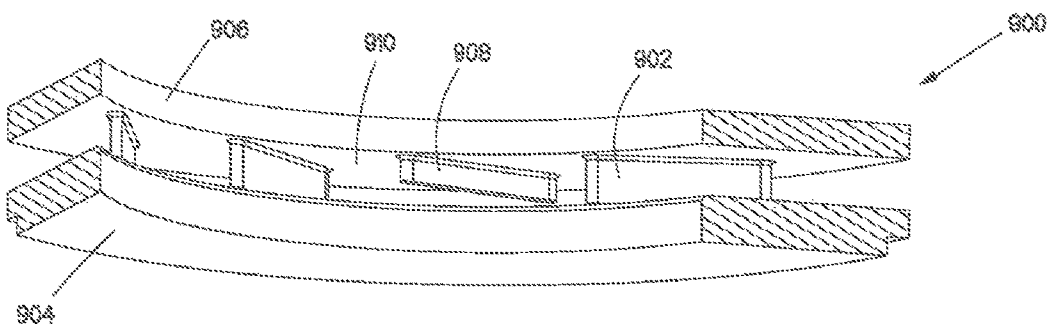
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FIG. 9

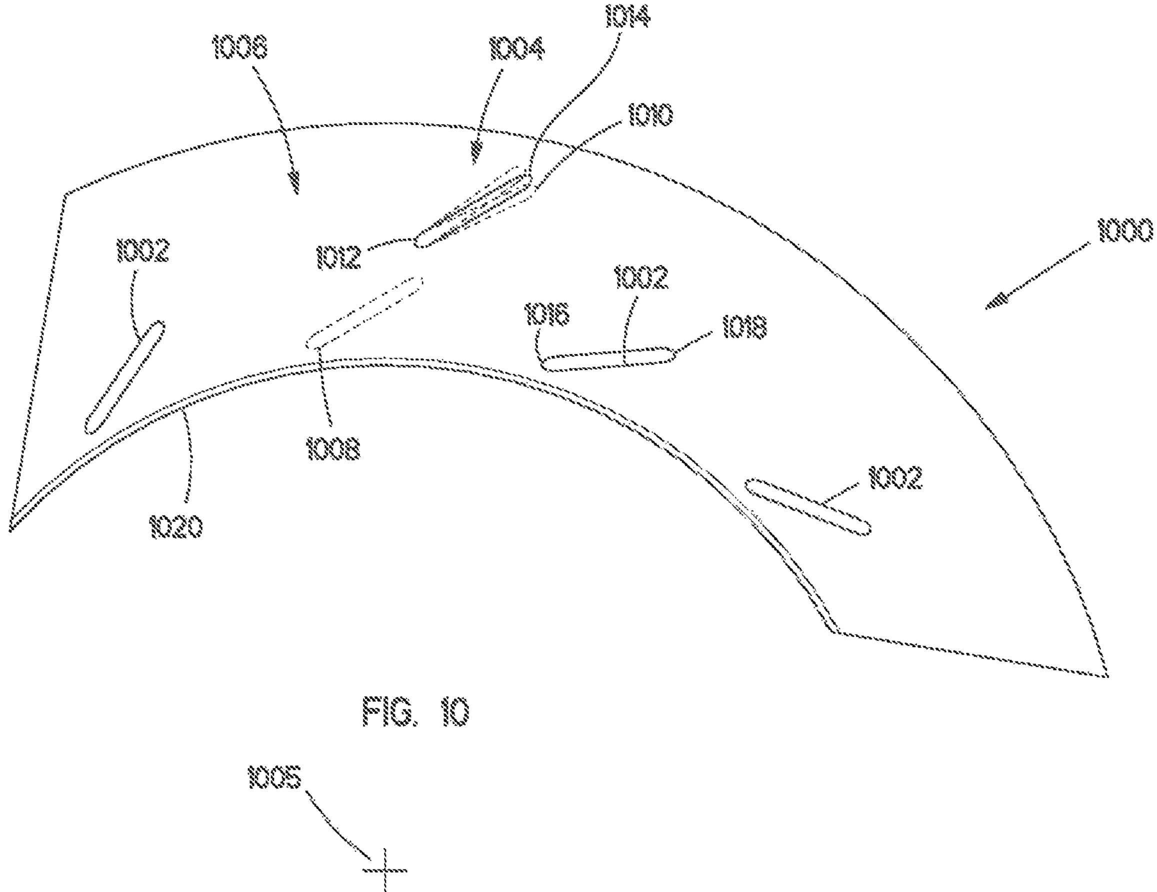
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FIG. 10

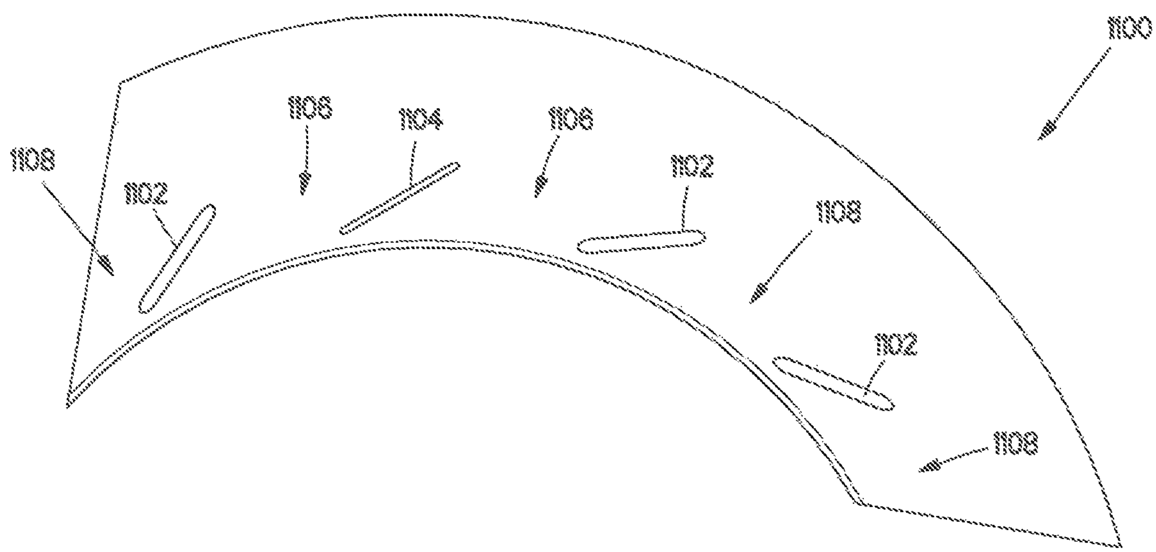


FIG. 11

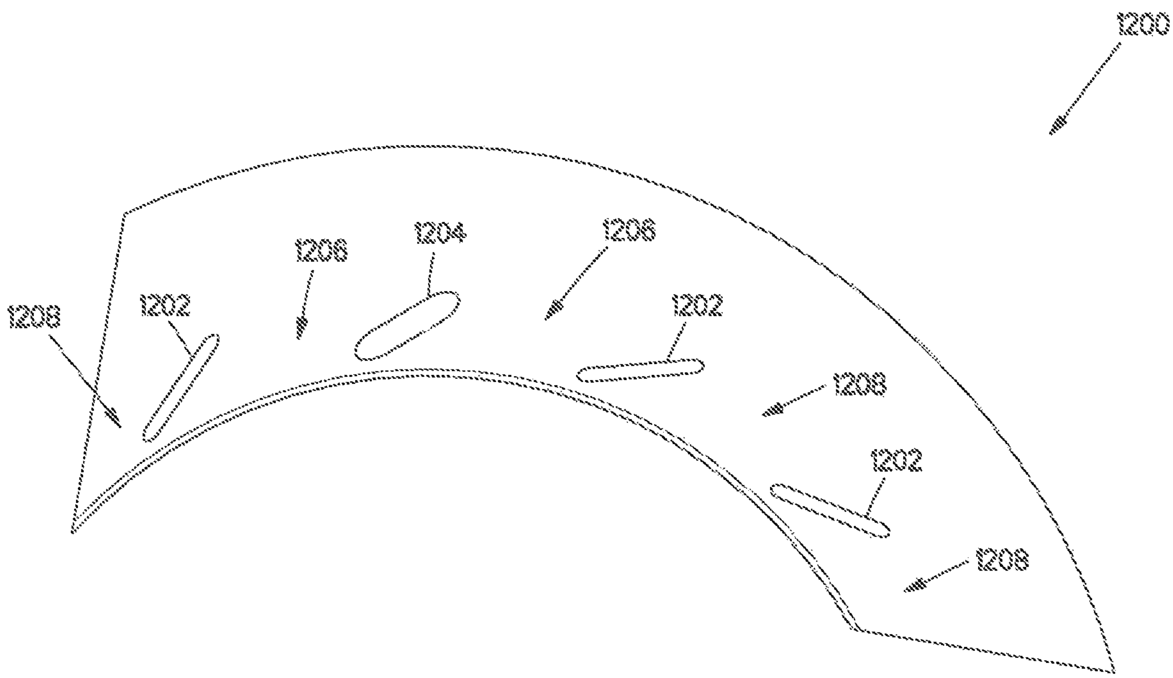


FIG. 12

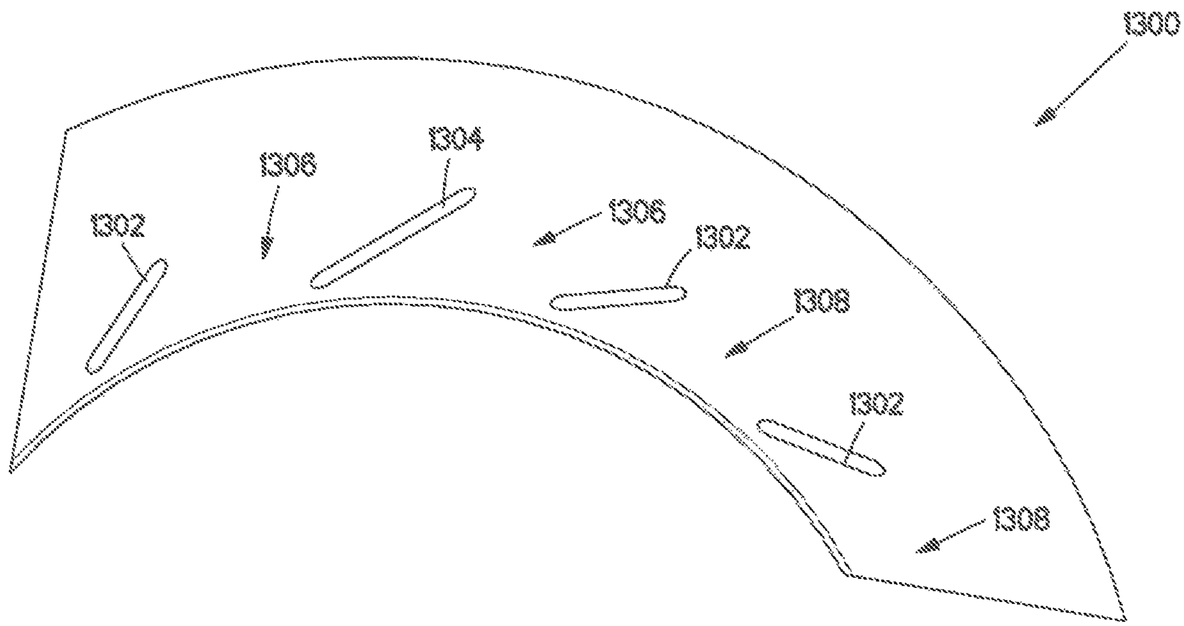


FIG. 13

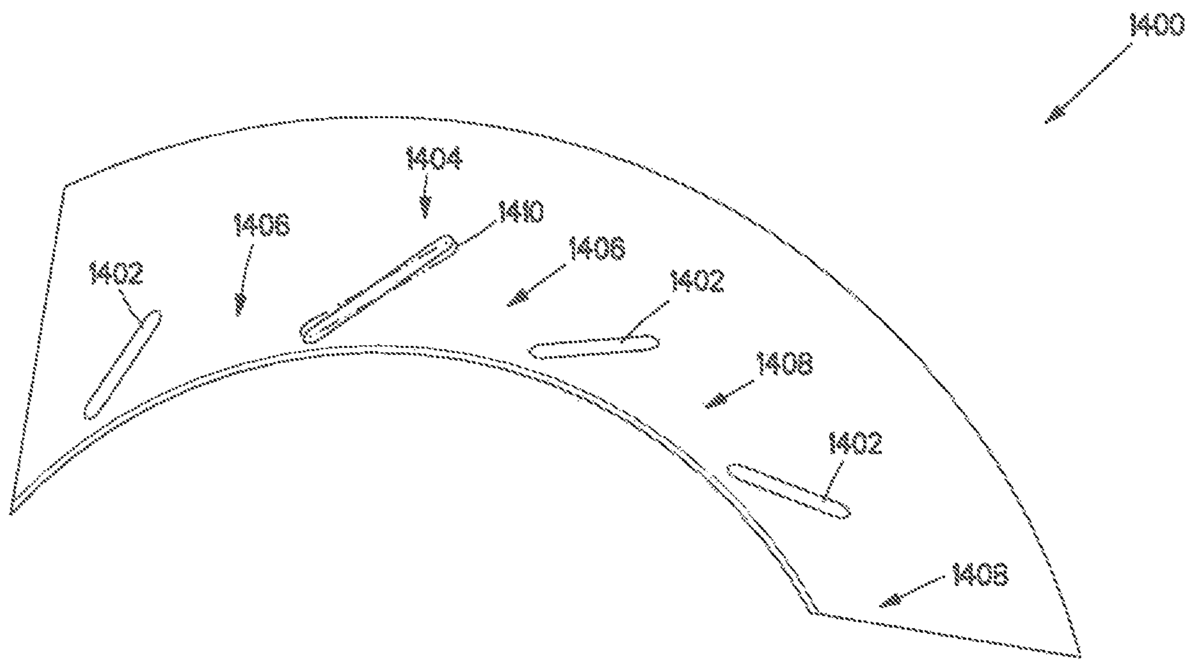


FIG. 14

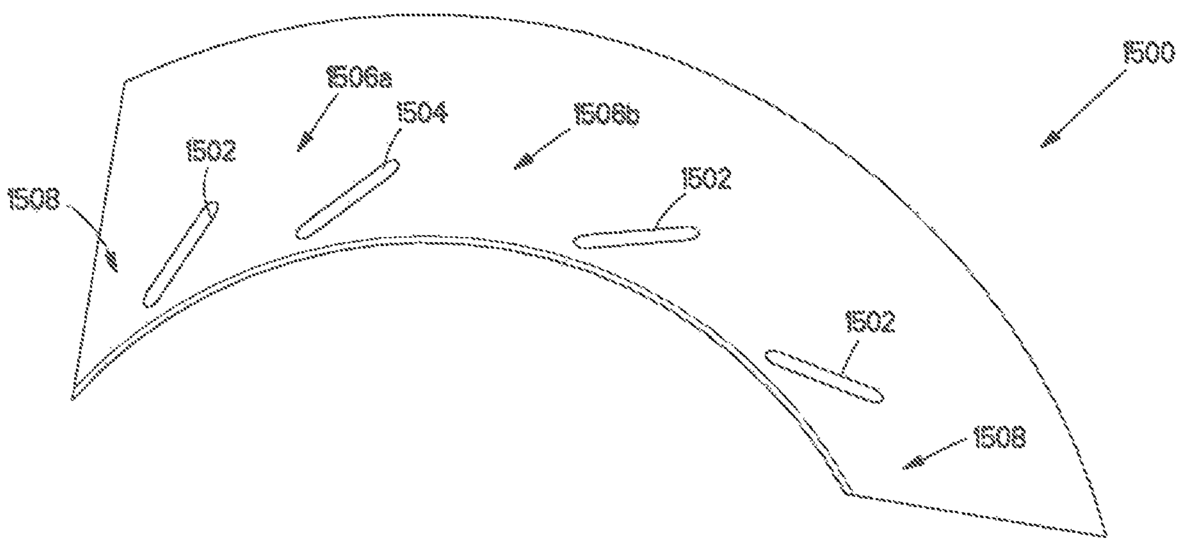
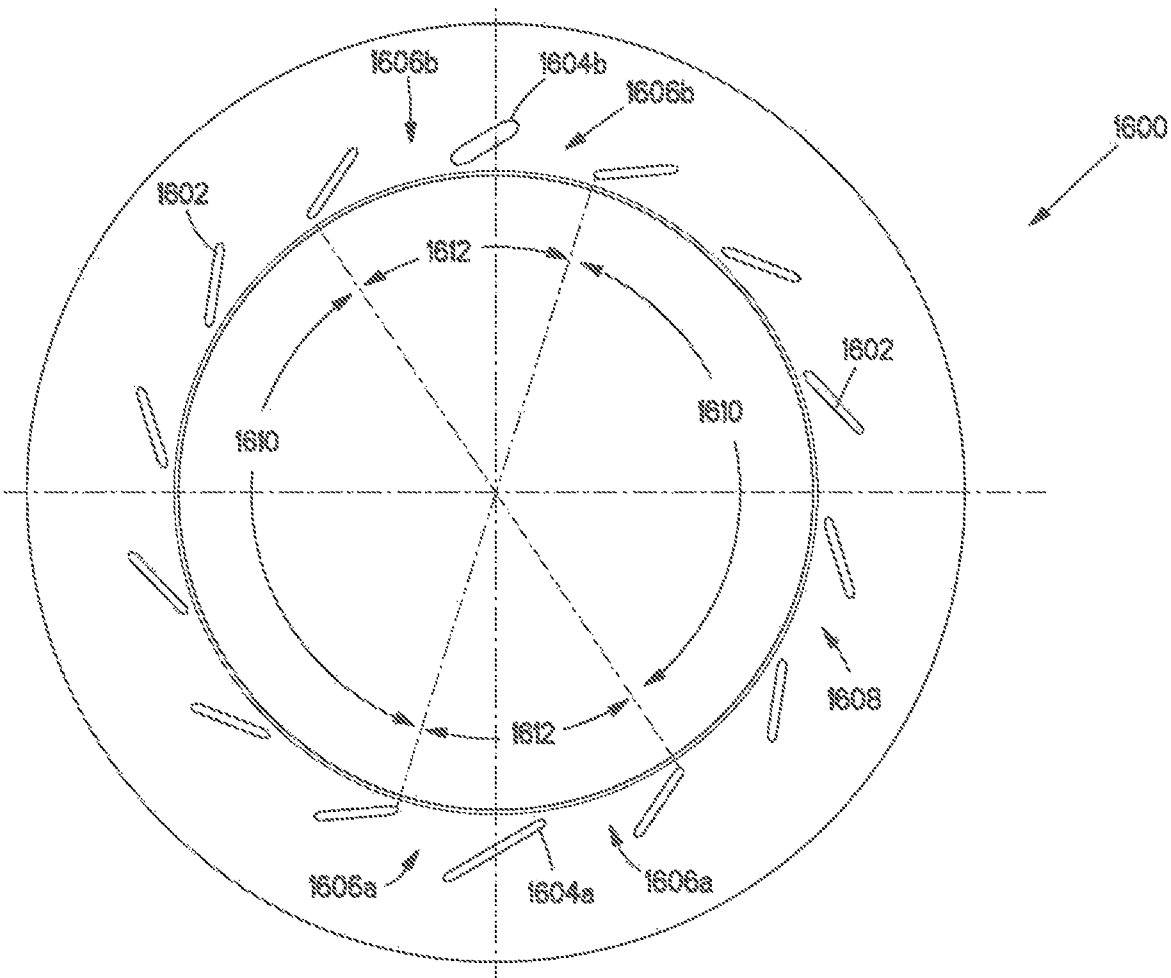


FIG. 15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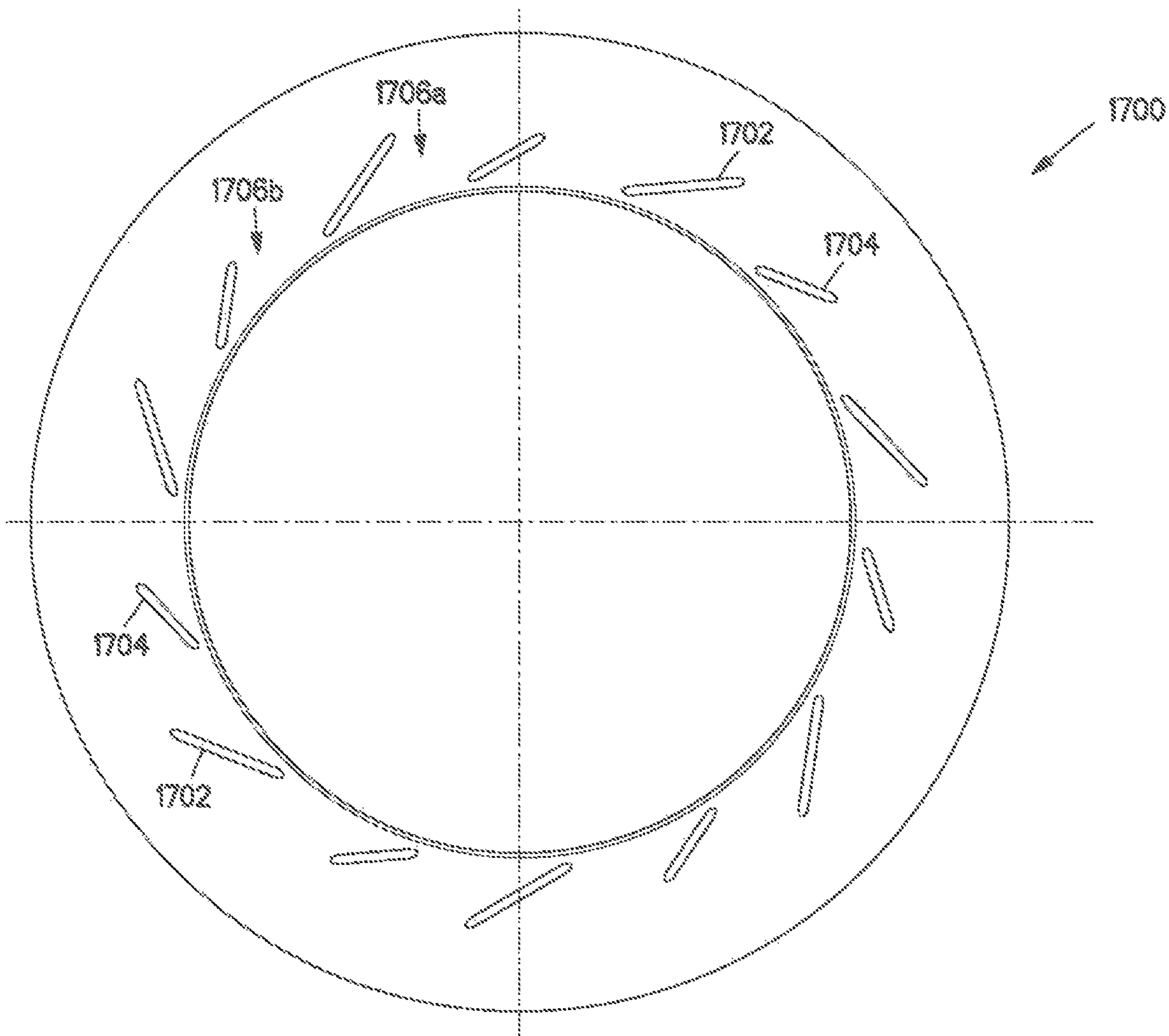
1606a
1604a
1606a

FIG. 16



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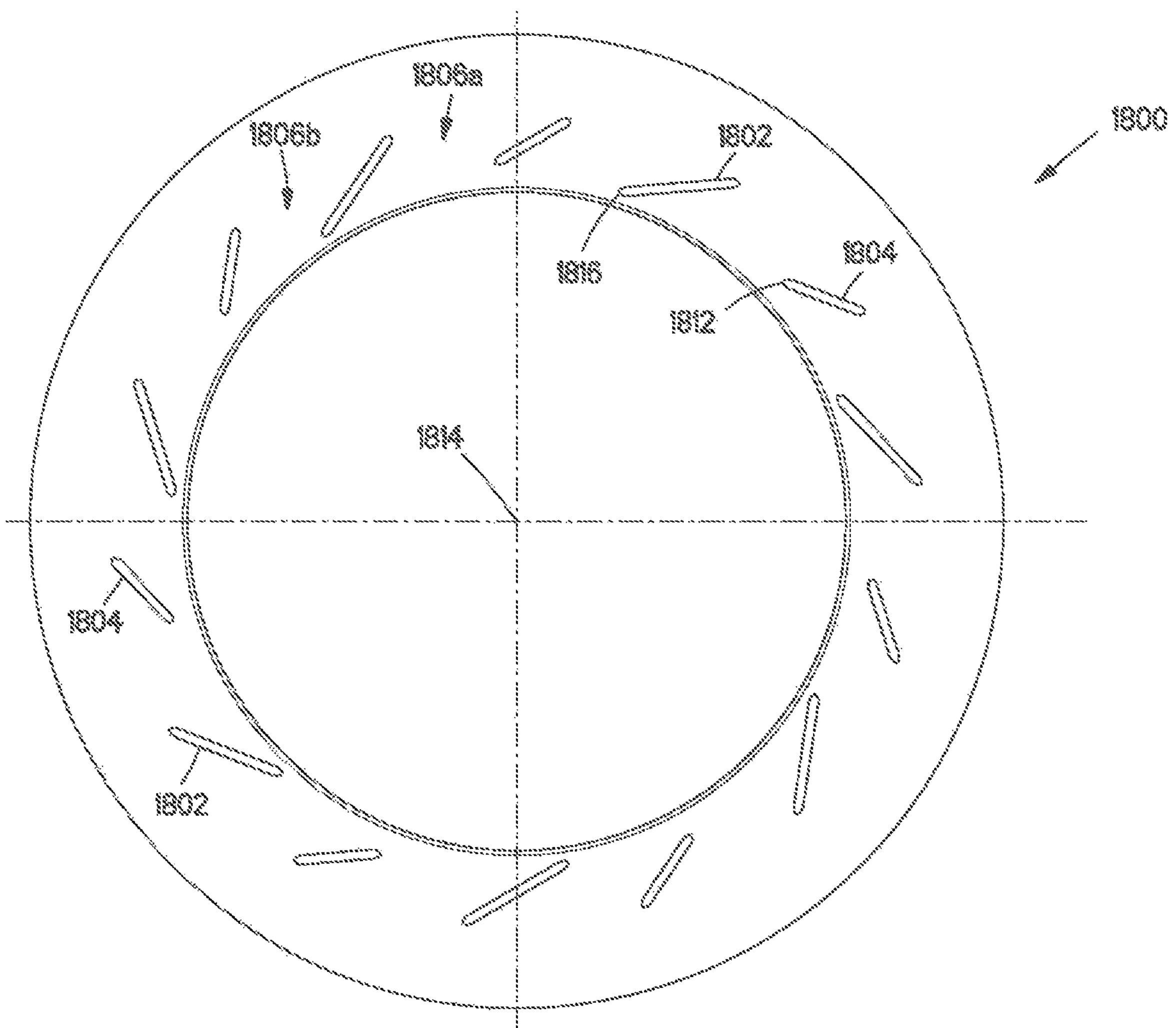

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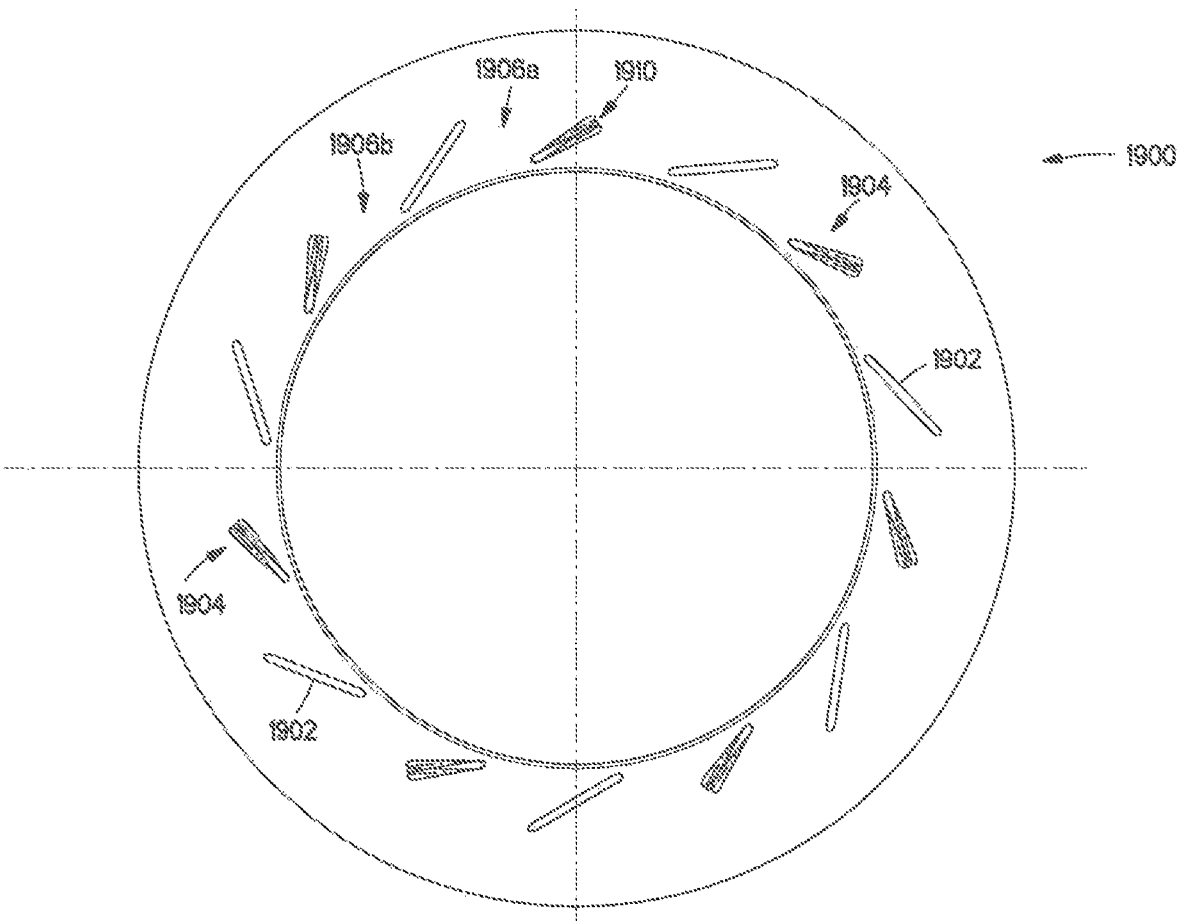


FIG. 19

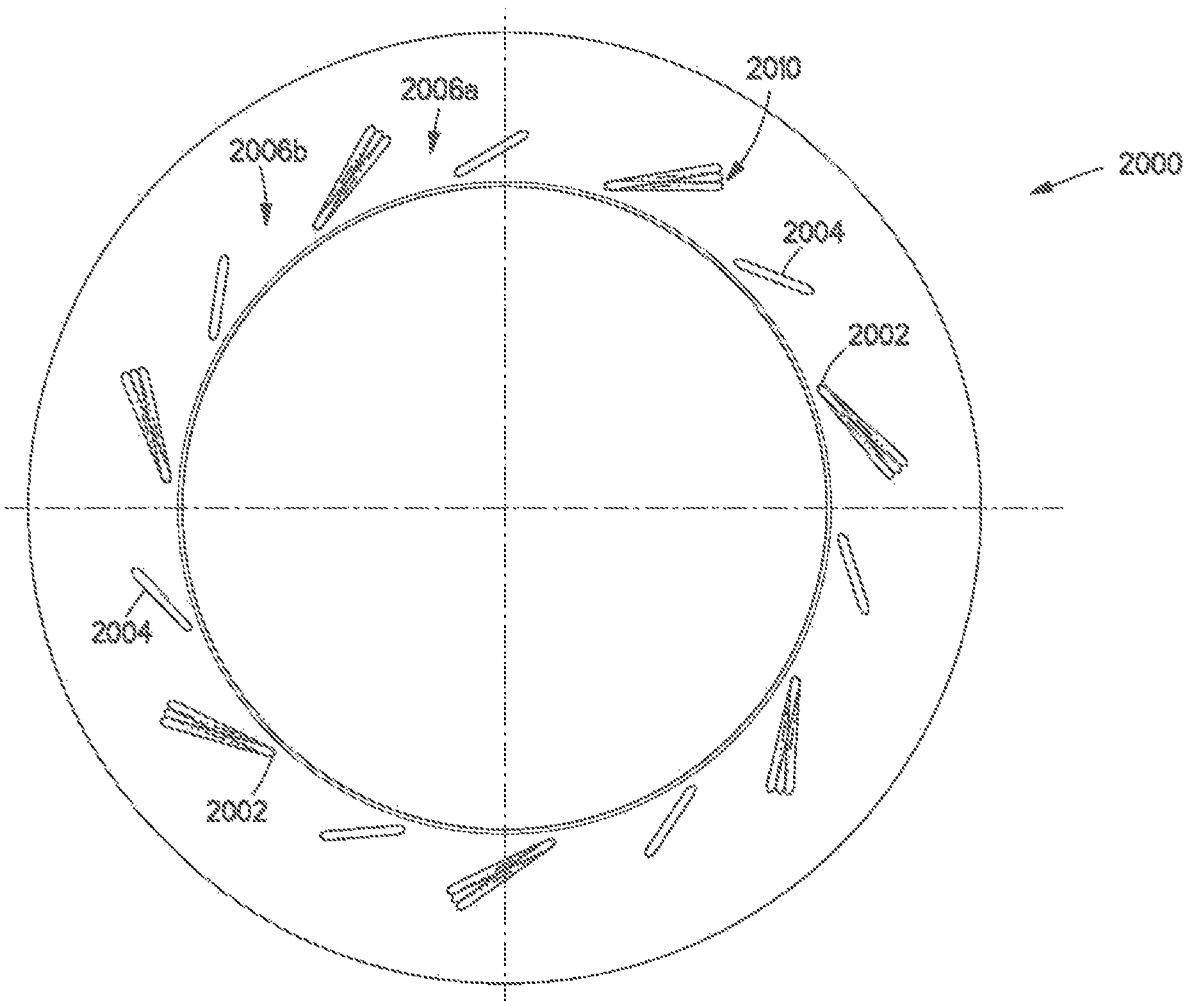


FIG. 20

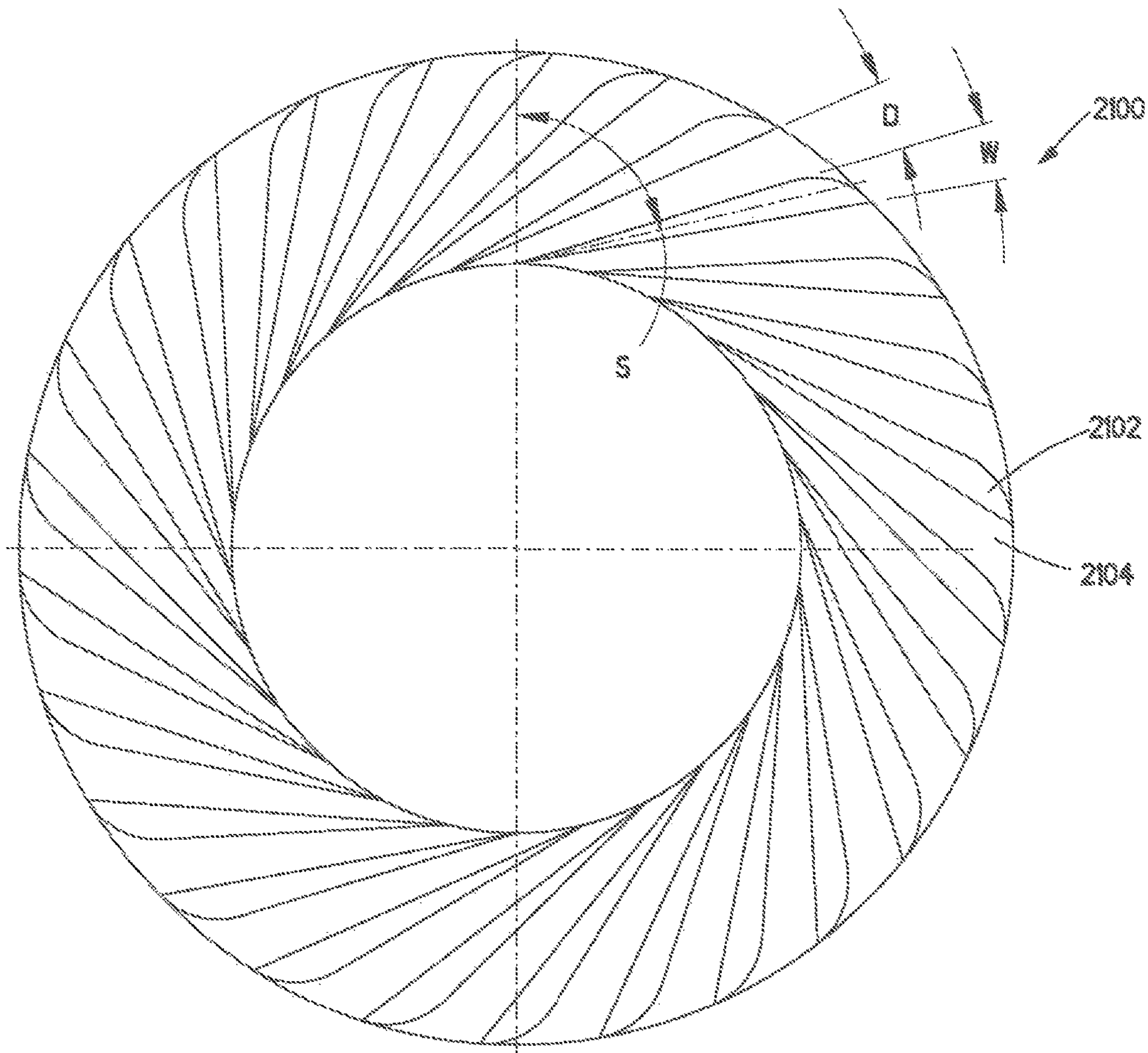


FIG. 21 (Prior Art)

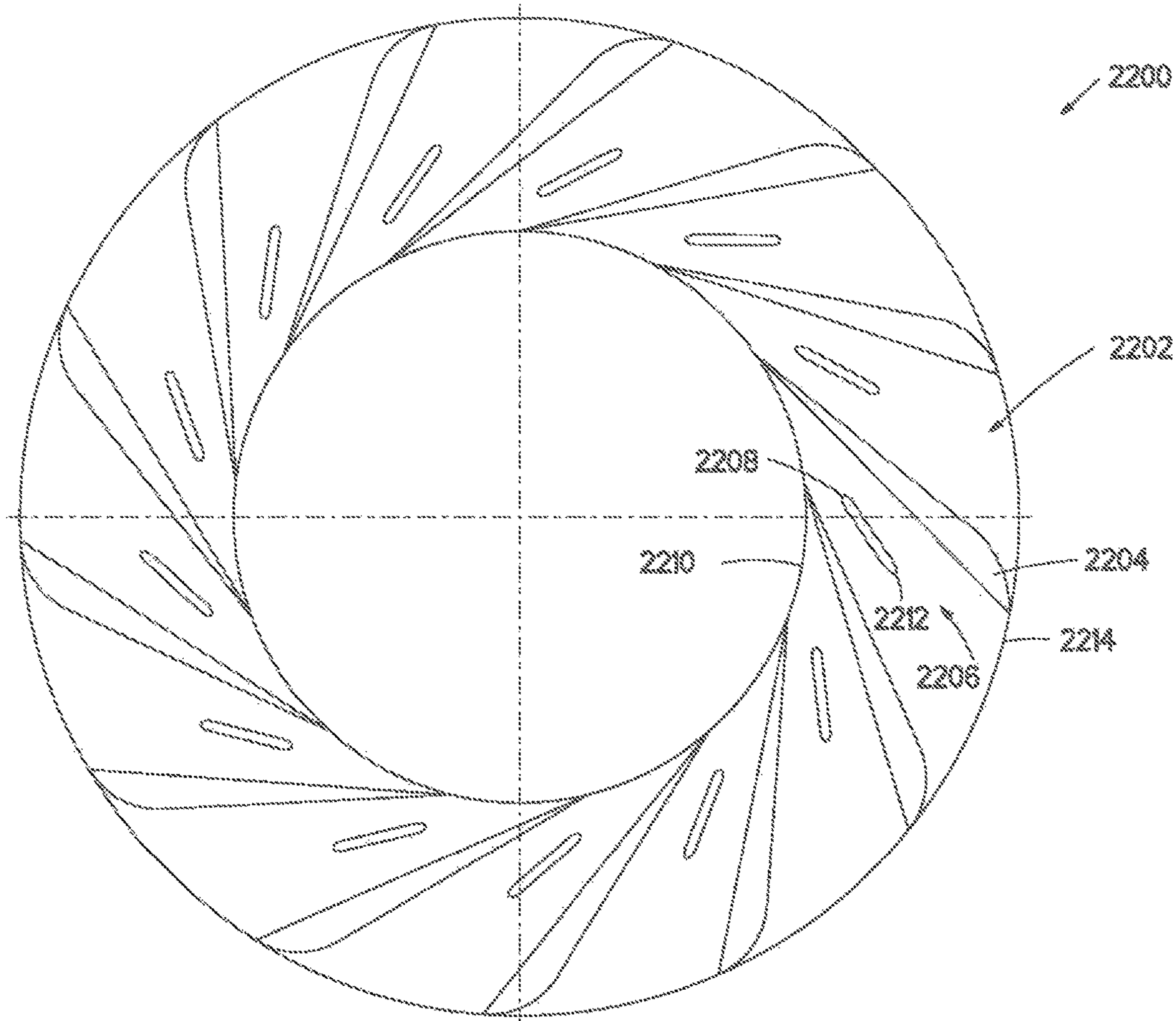


FIG. 22

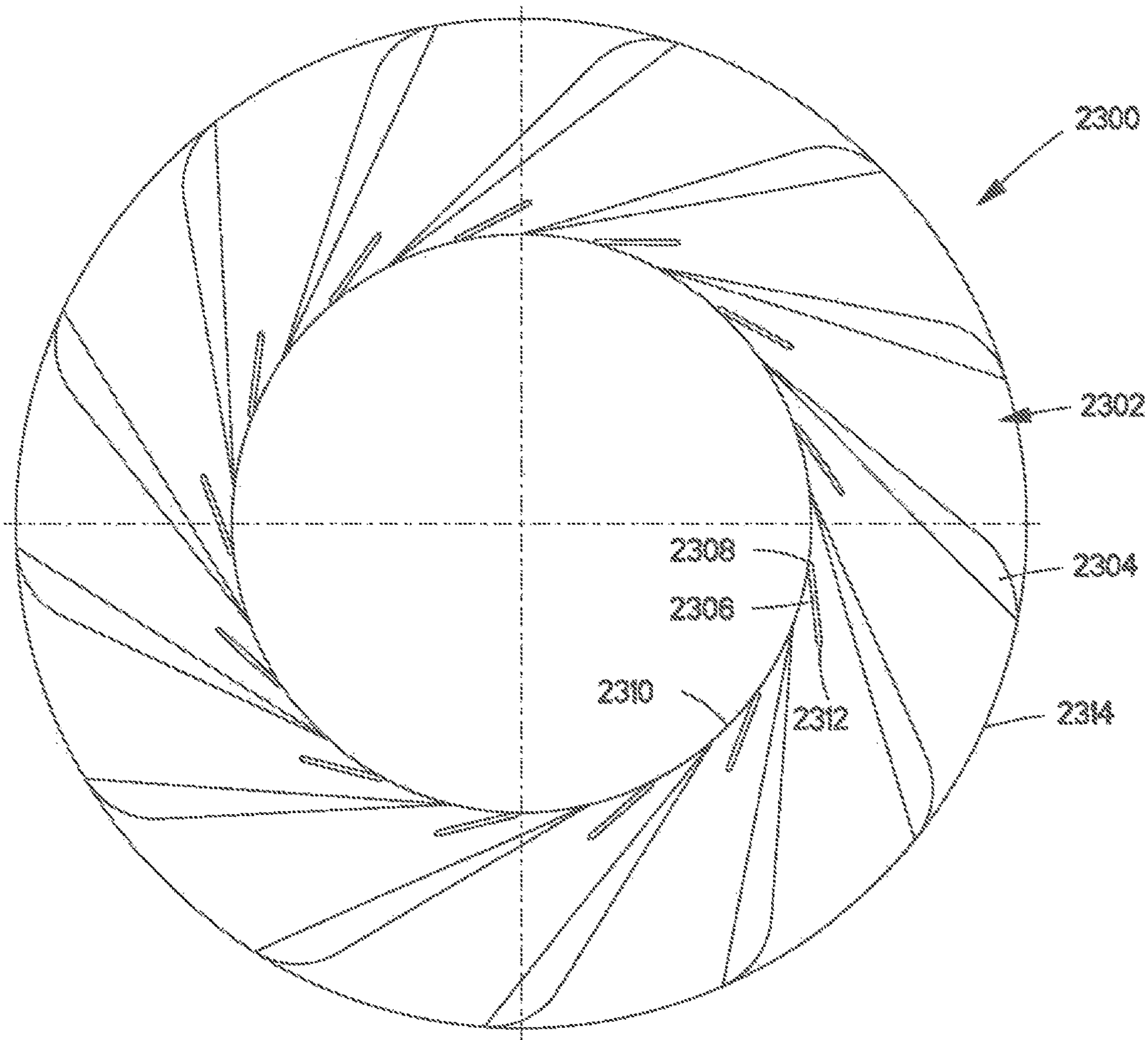


FIG. 23

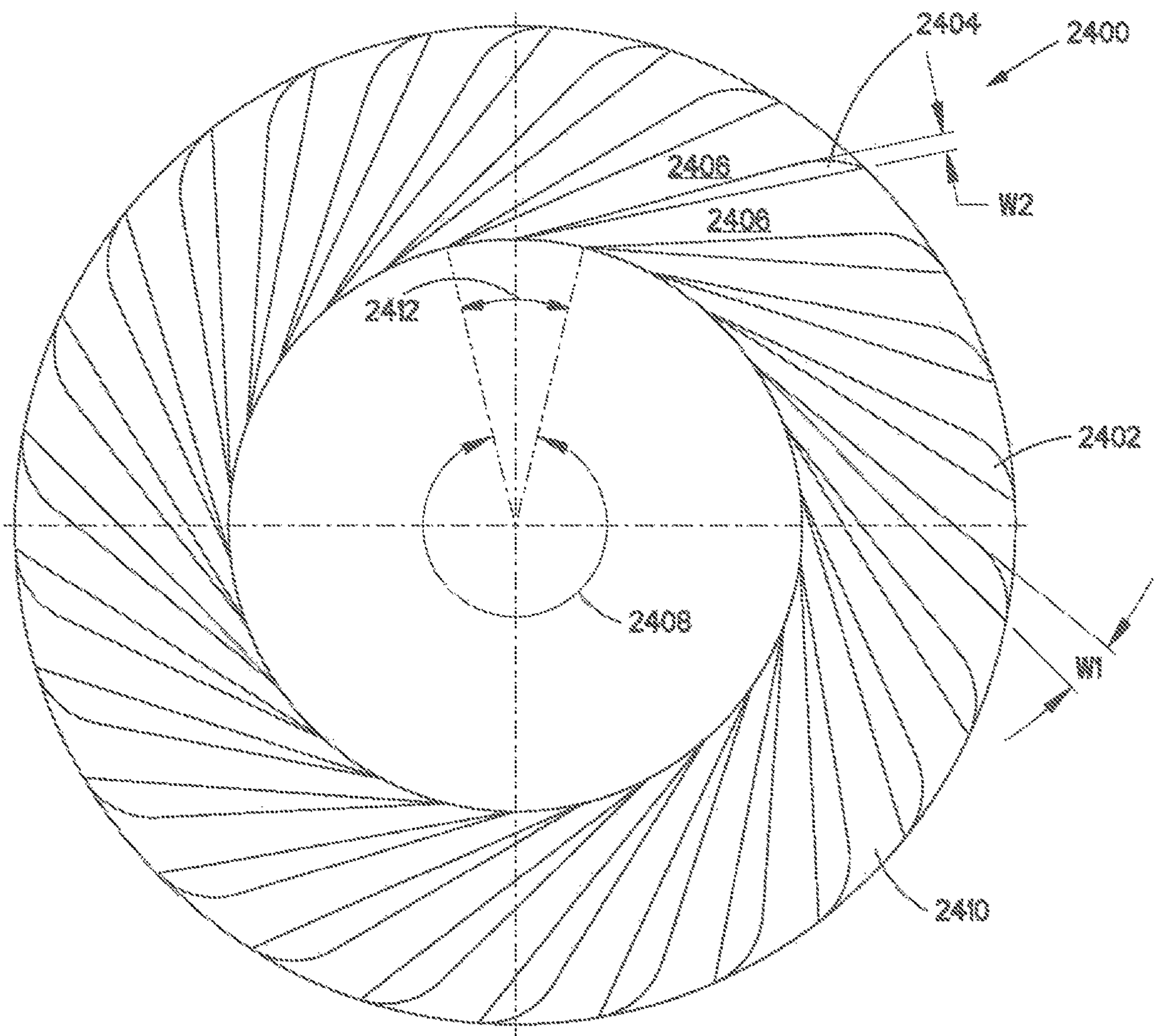


FIG. 24

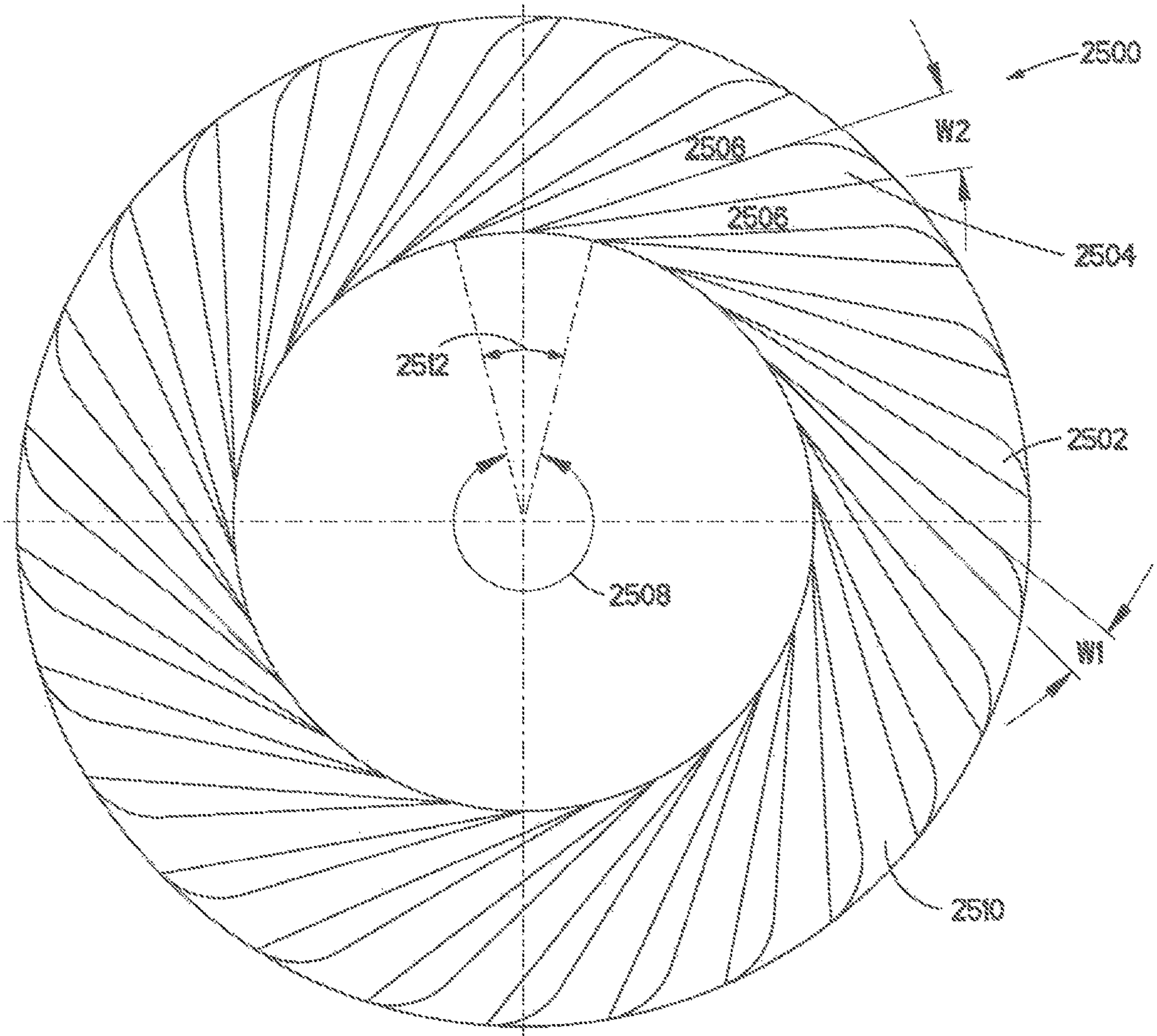


FIG. 25

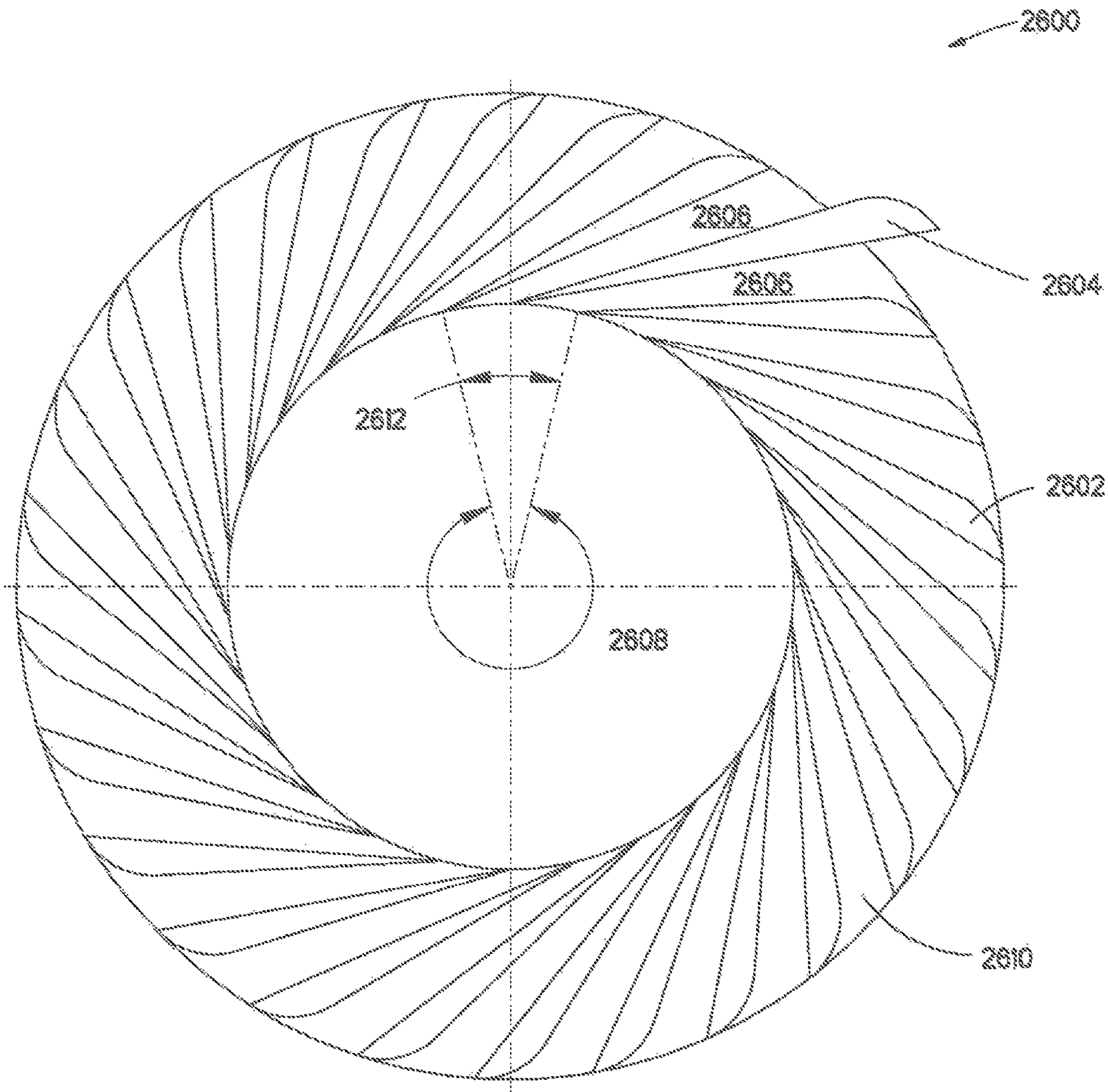


FIG. 26

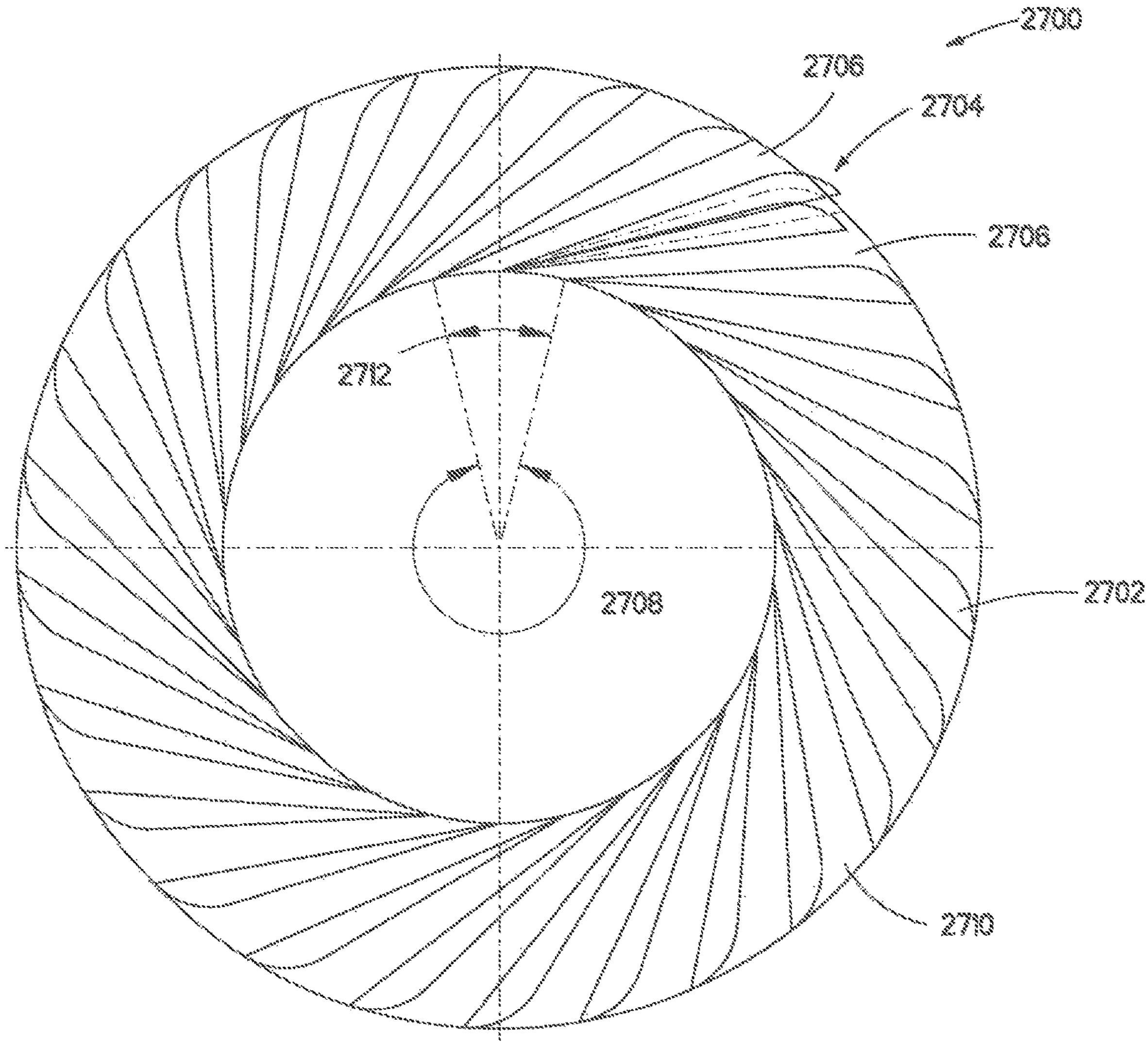


FIG. 27

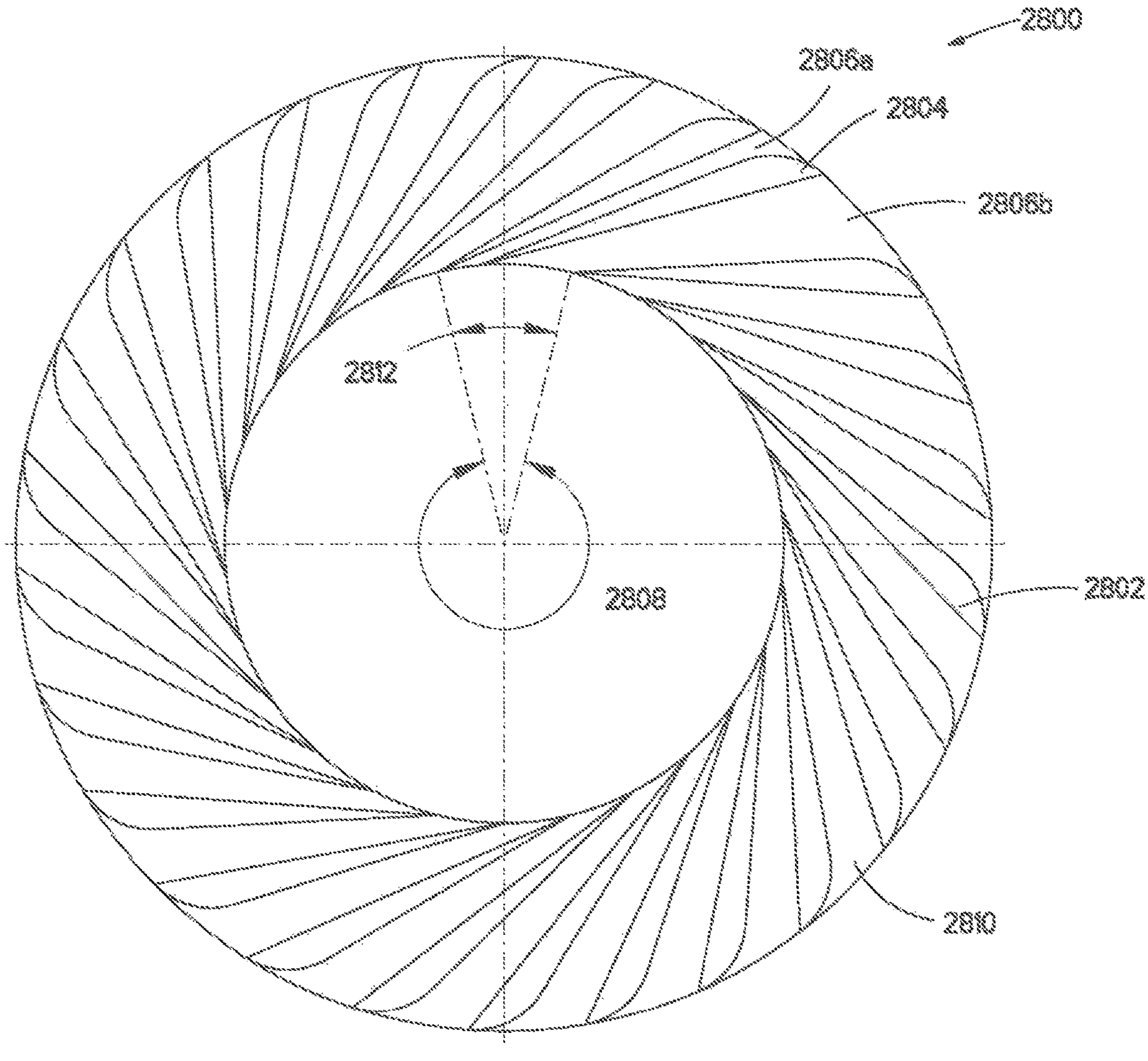
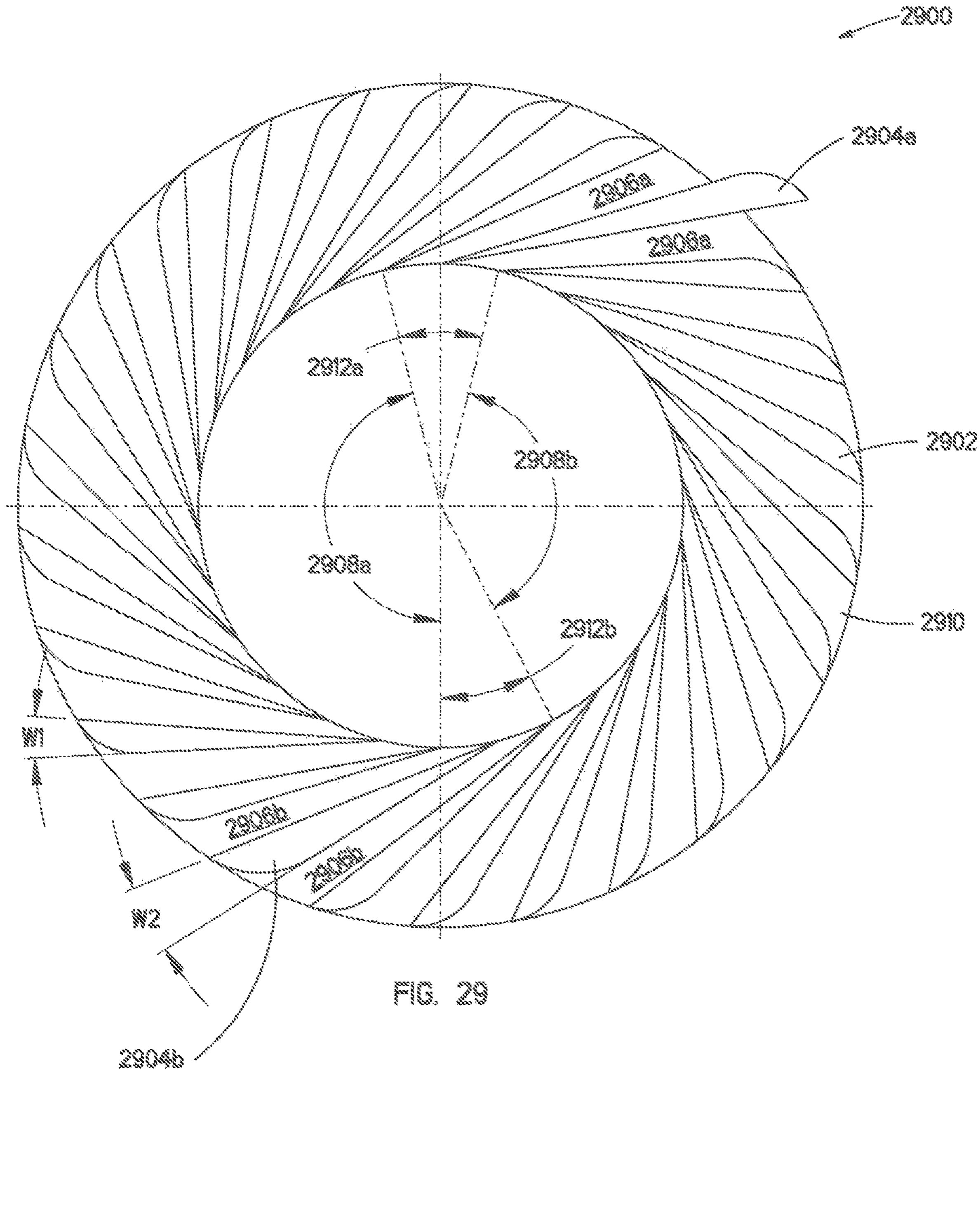


FIG. 28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2904a
2906a
2906a
2912a
2908b
2902
2908a
2910
2912b
W1
2906b
2906b
W2
2904b

FIG. 29

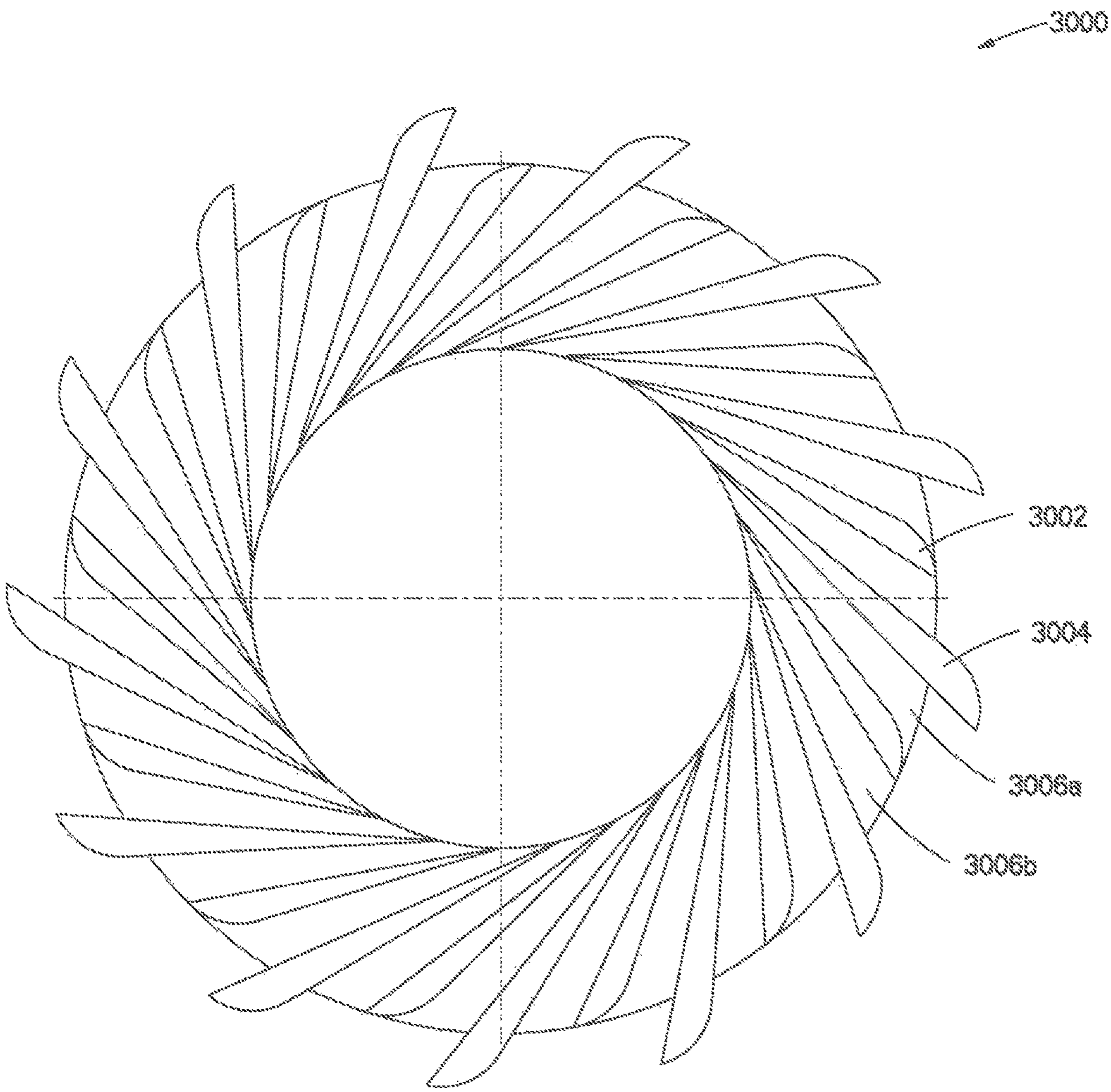

FIG. 30

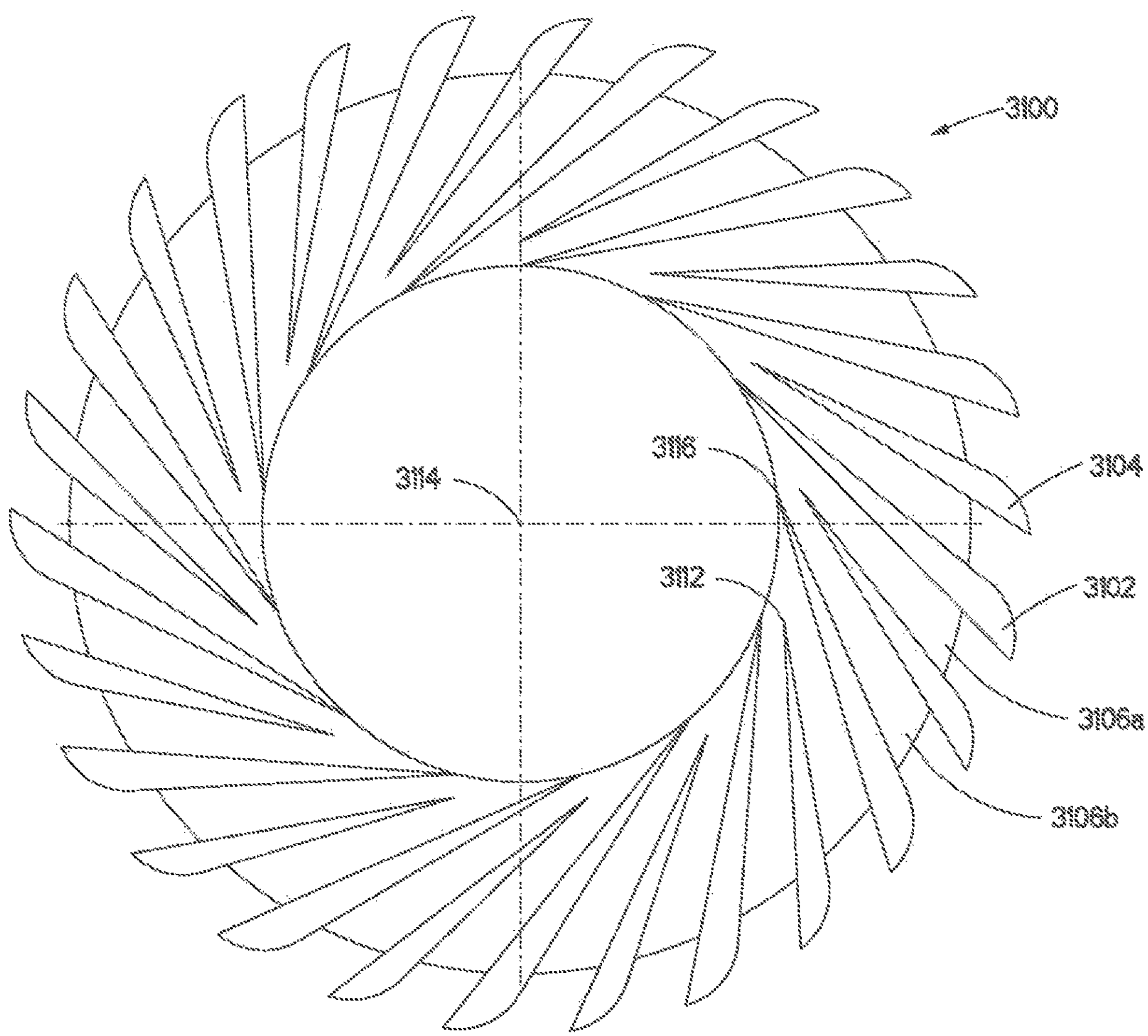

FIG. 31

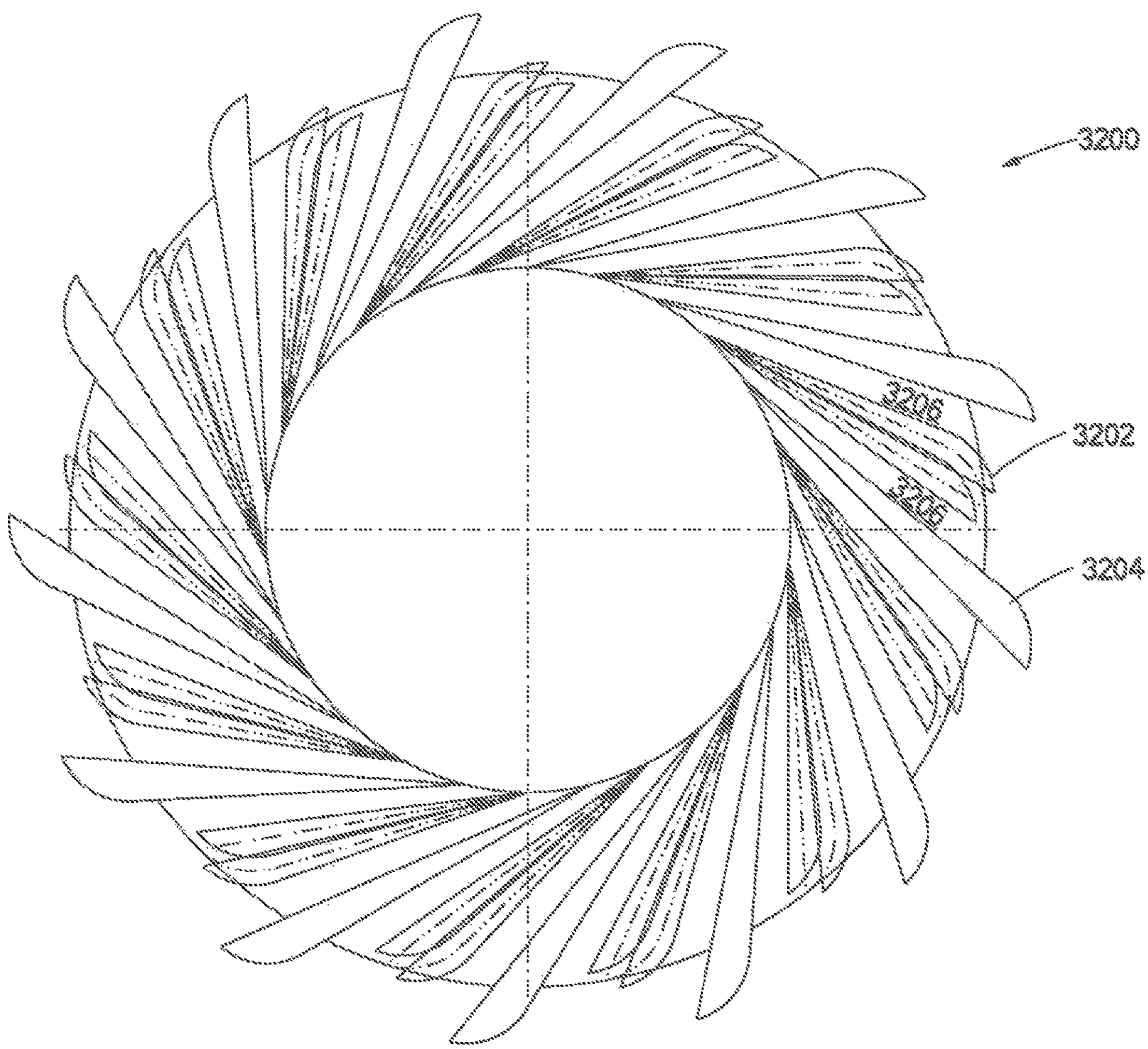

FIG. 32

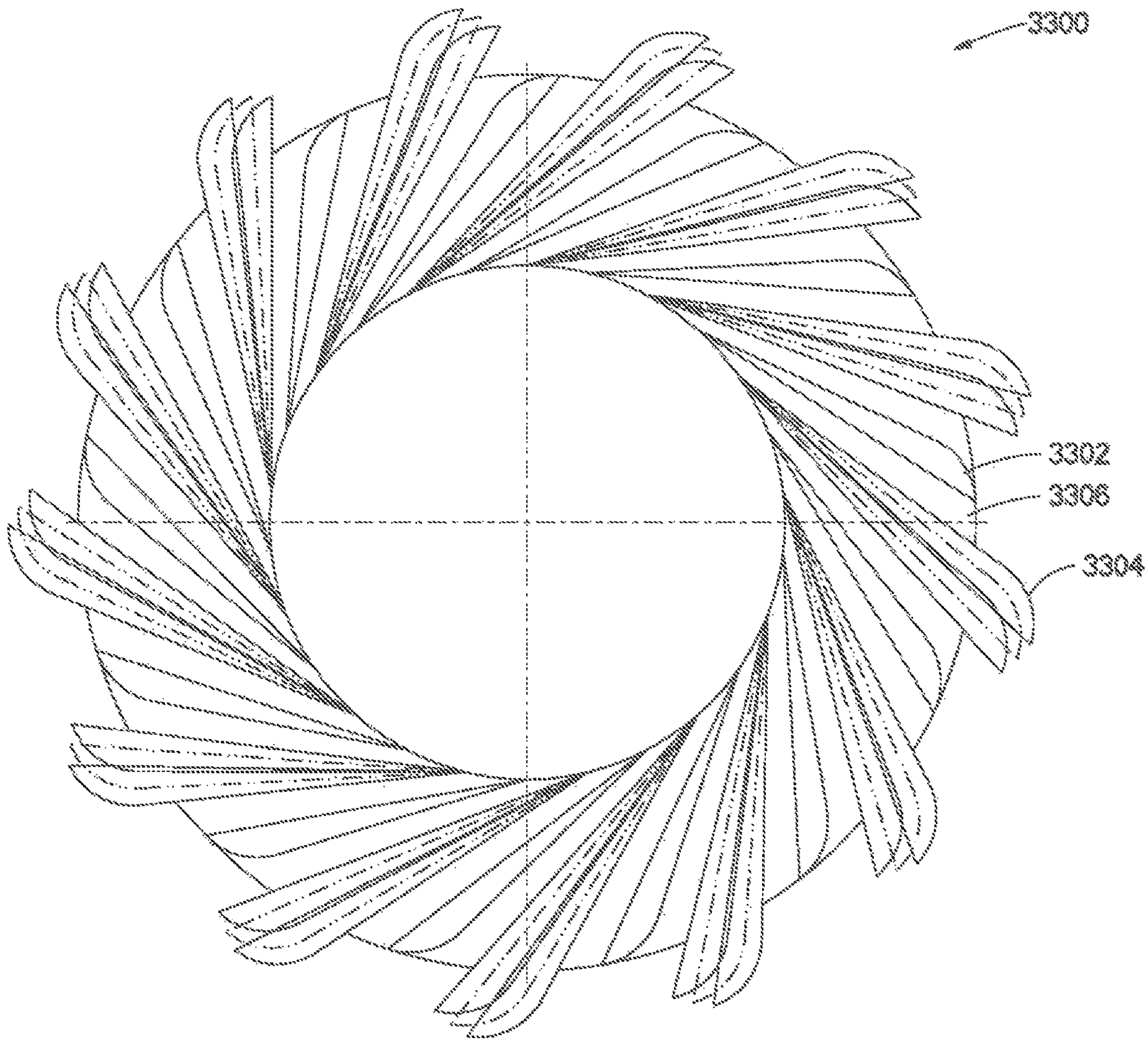

FIG. 33

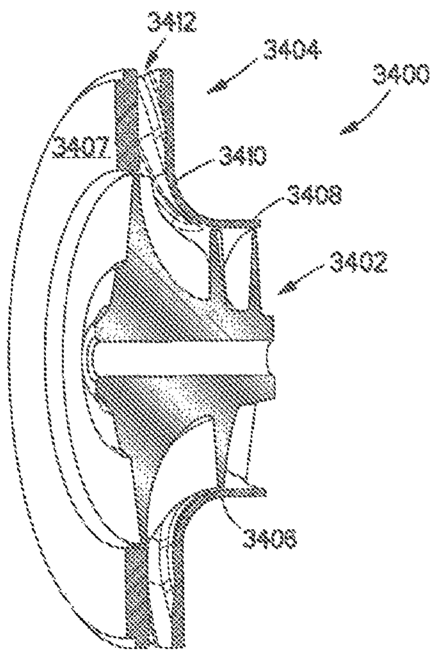
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FIG. 34

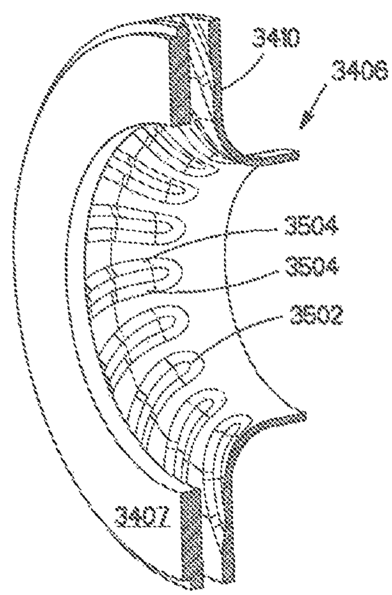
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FIG. 35

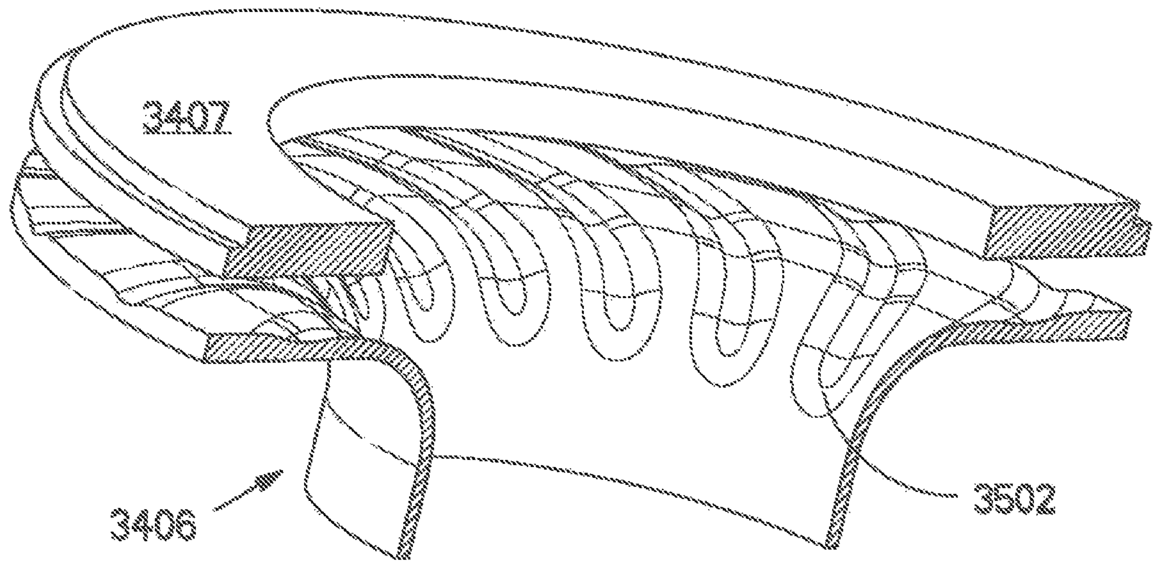

FIG. 36

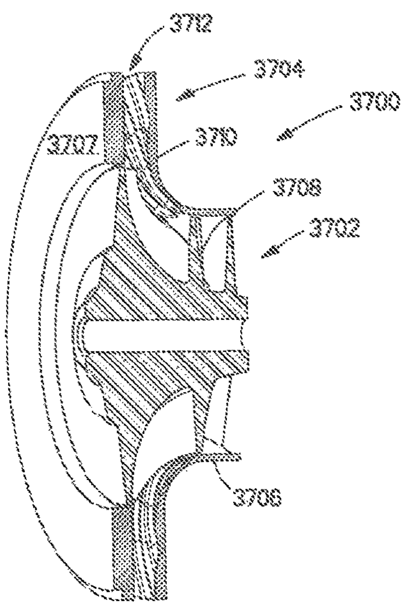
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FIG. 37

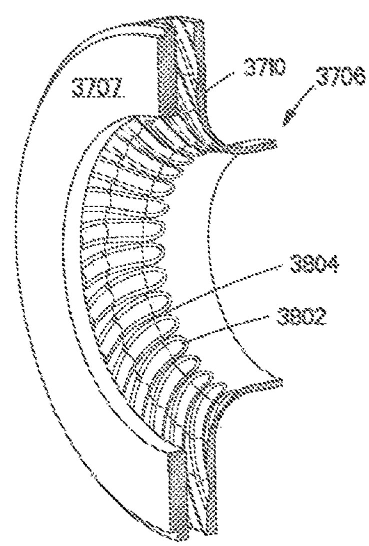
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FIG. 38

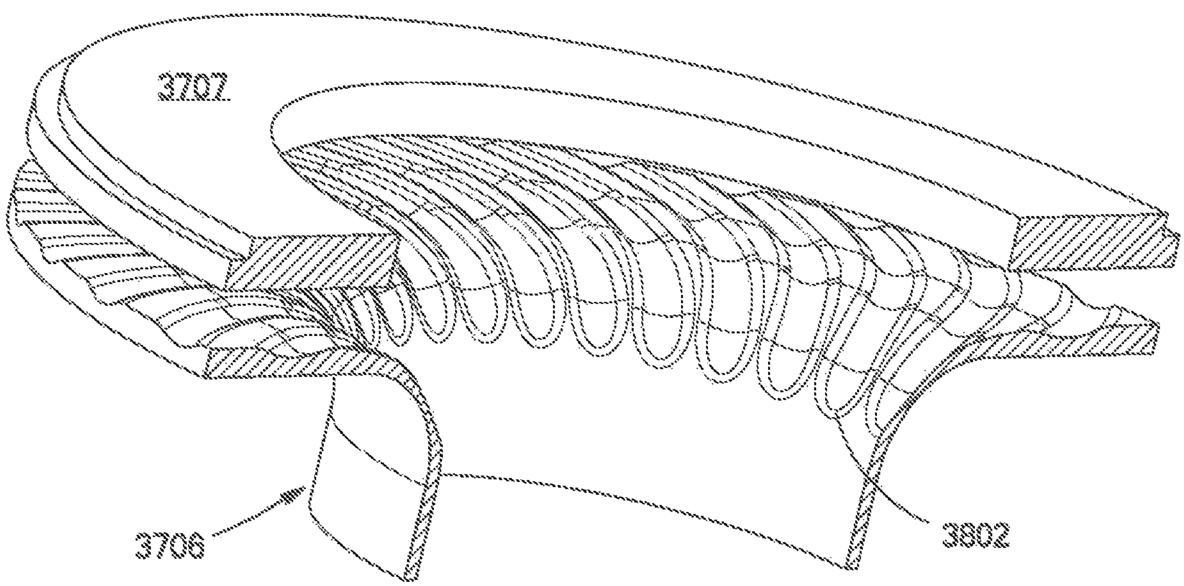

FIG. 39

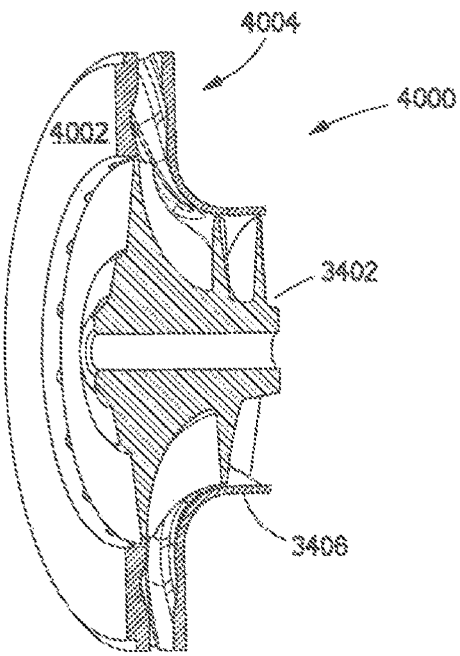

FIG. 40

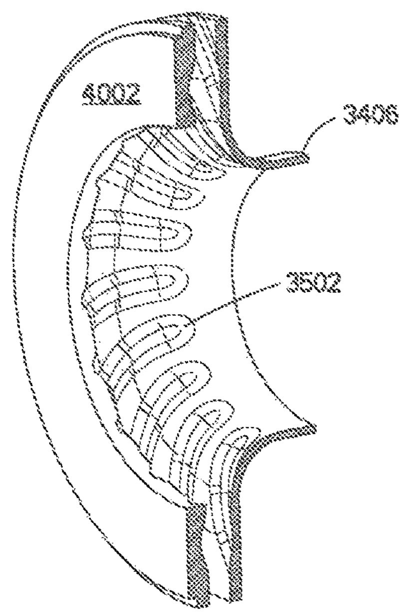

FIG. 41

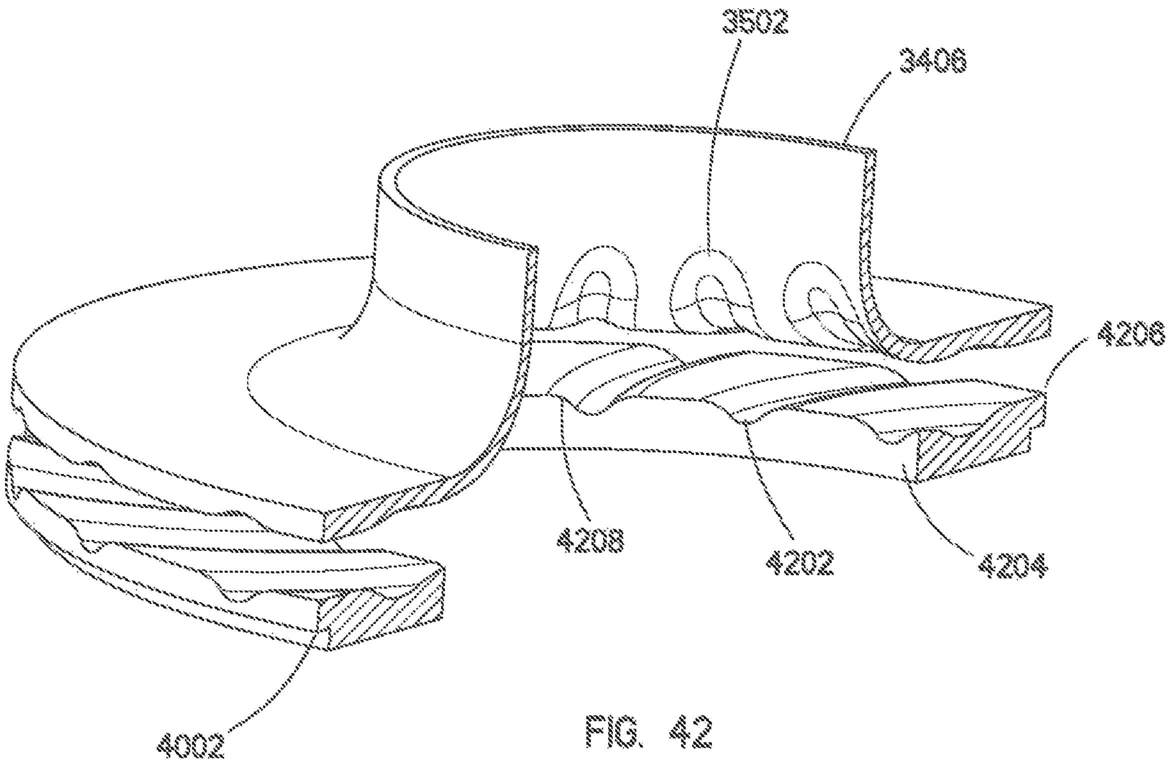

FIG. 42

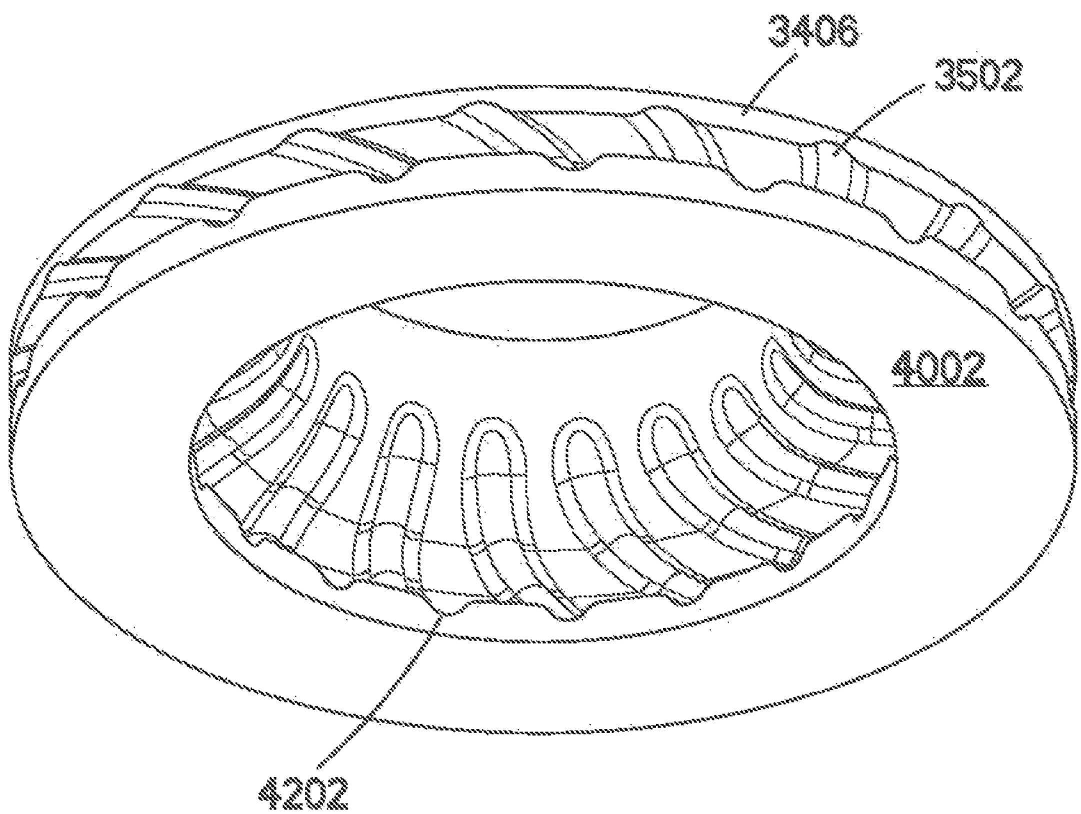

FIG. 43

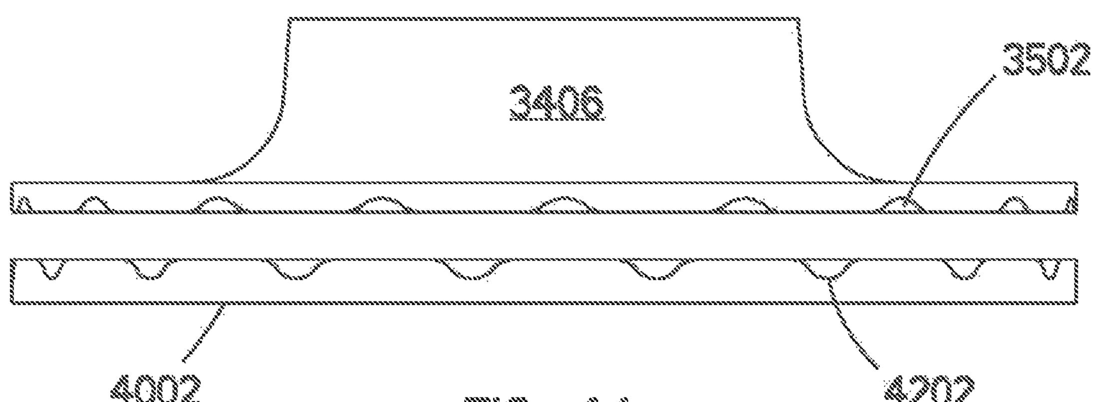

FIG. 44

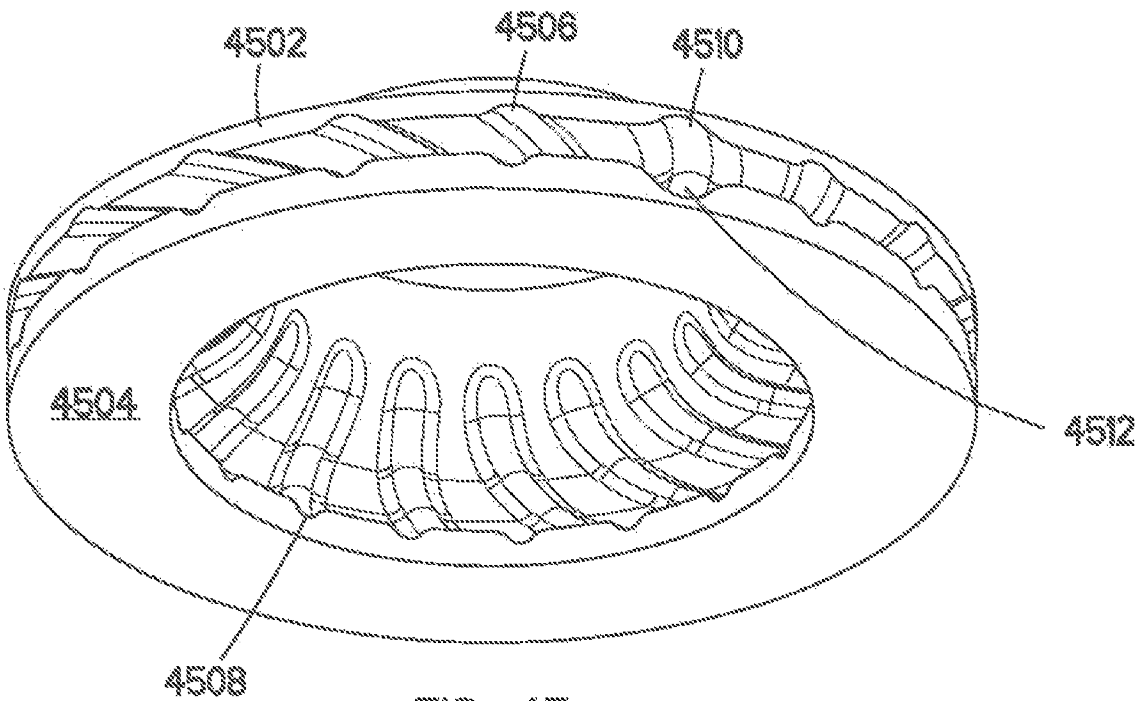

FIG. 45

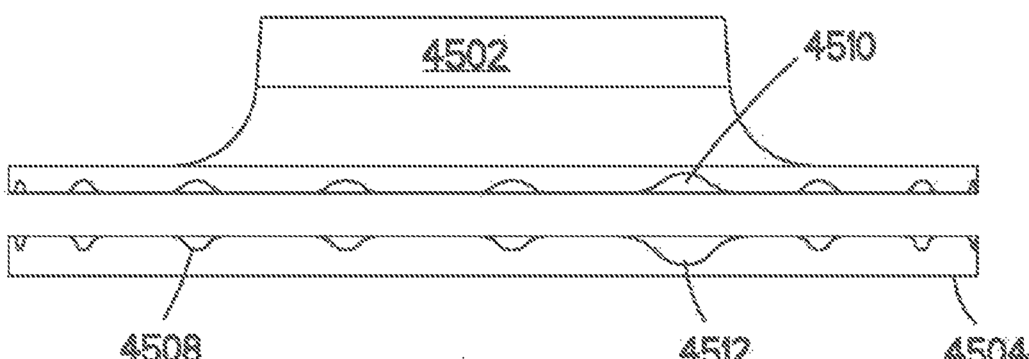

FIG. 46

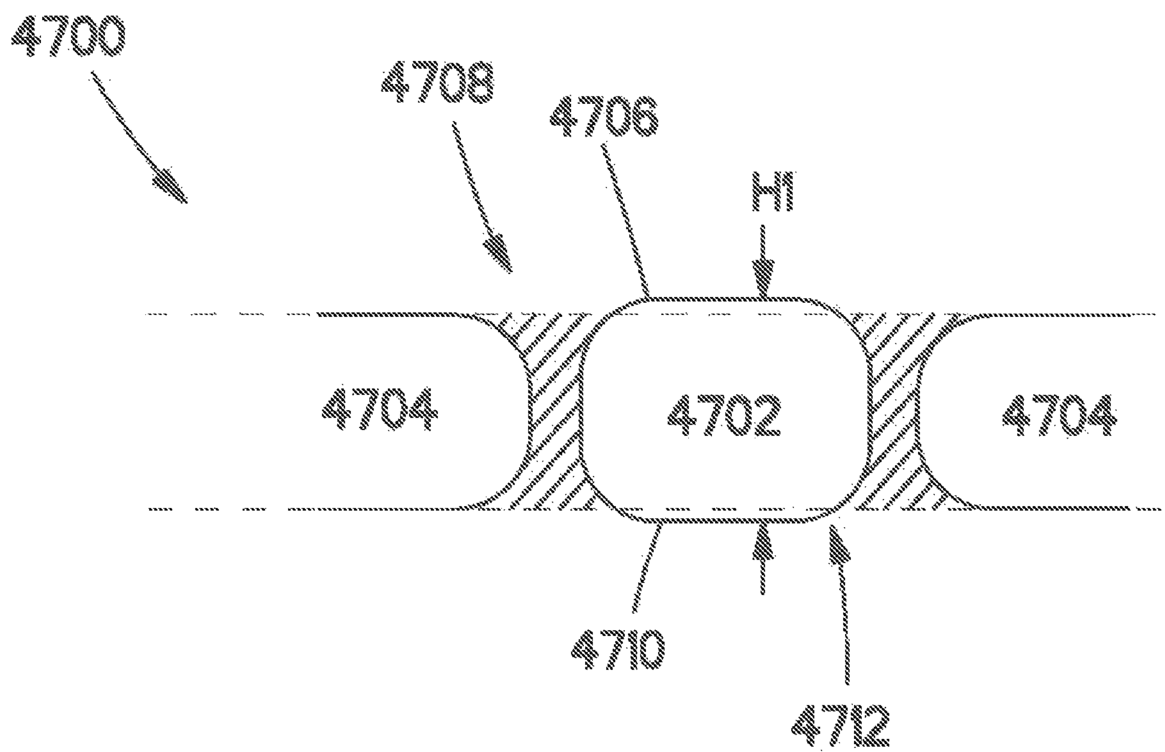

FIG. 47

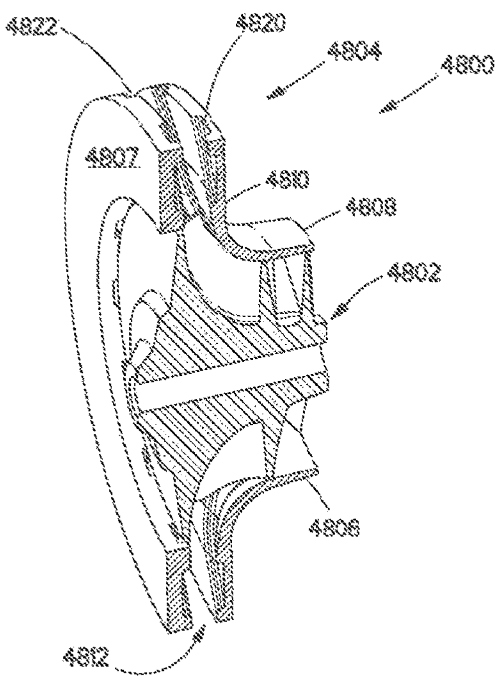
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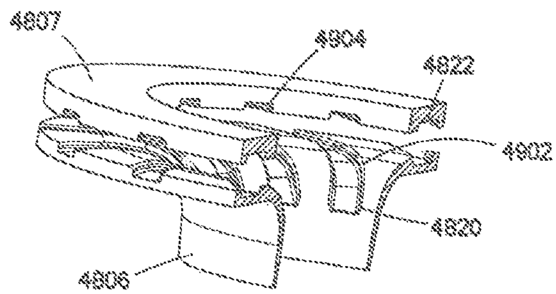
FIG. 48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4806

FIG. 49

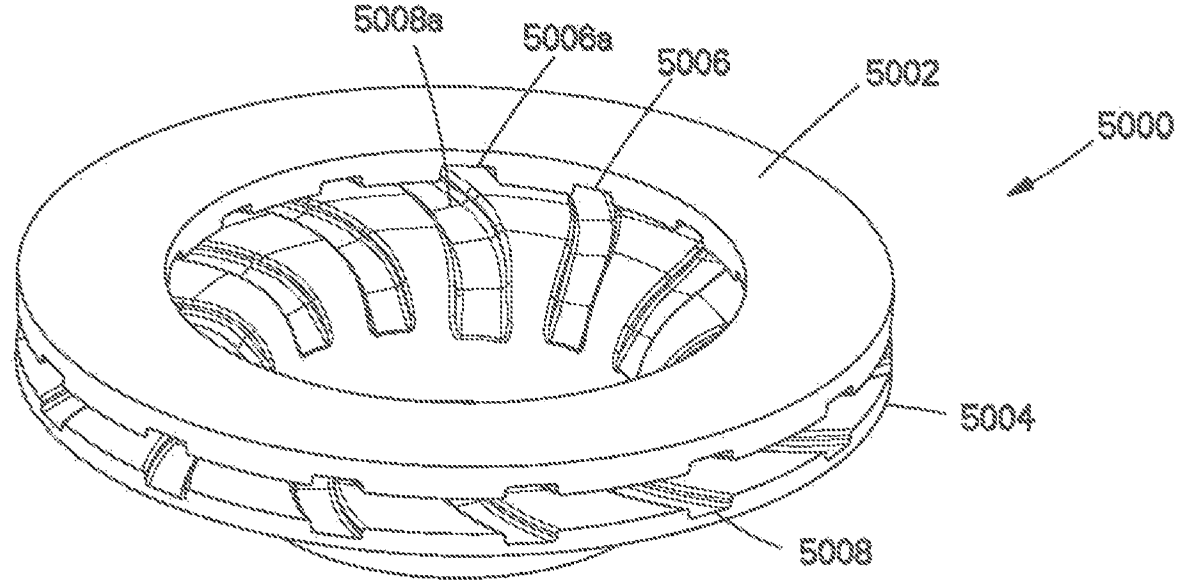
5008a
5006a
5006
5002
5000
5004
5008

FIG. 50

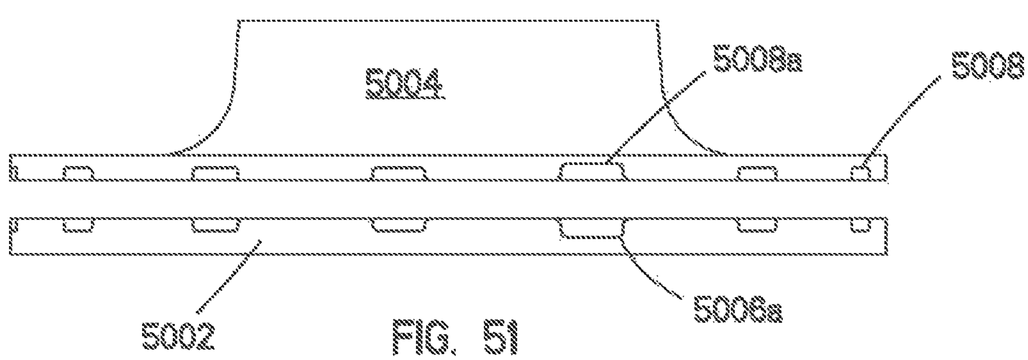
5004
5008a
5008
5002
5006a

FIG. 51

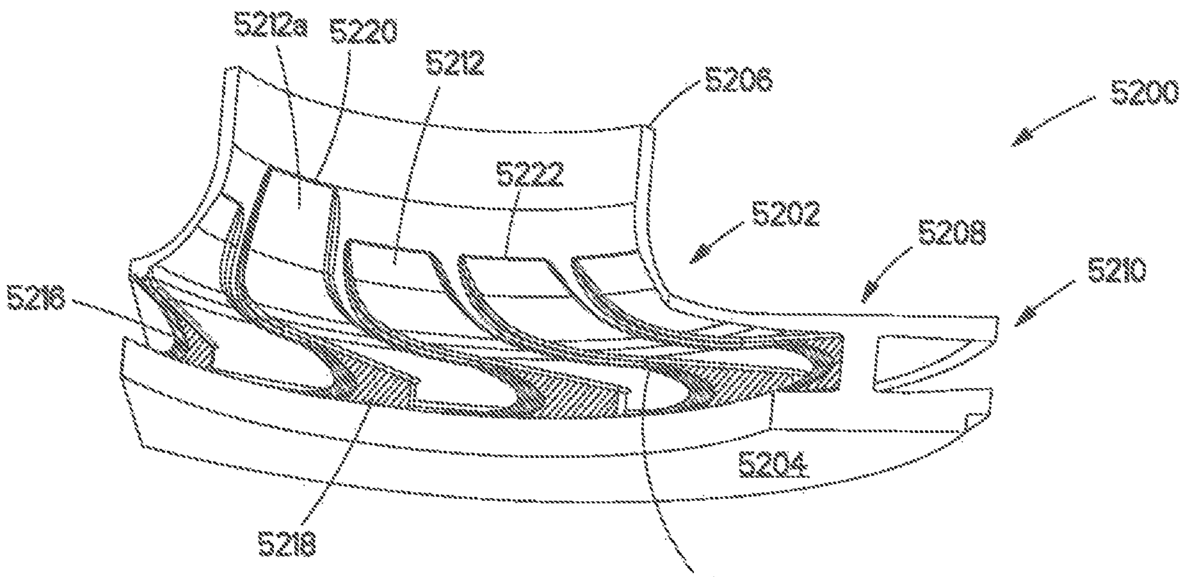
5212a
5220
5212
5206
5200
5222
5202
5208
5210
5216
5204
5218
5214

FIG. 52

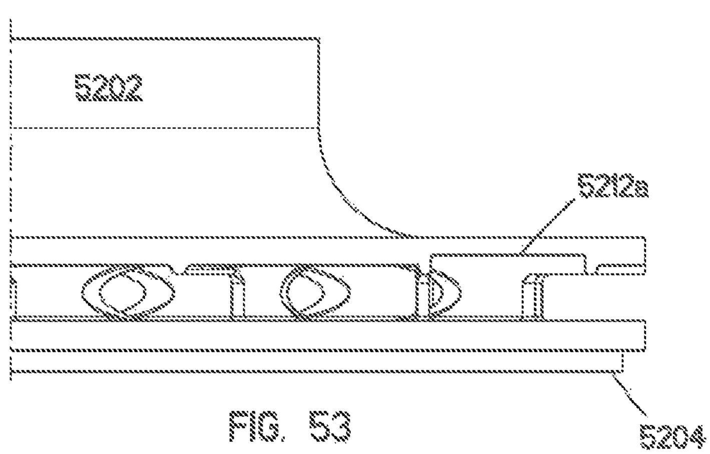
5202
5212a
5204

FIG. 53

BIASED PASSAGES FOR TURBOMACHINERY

RELATED APPLICATION DATA

This application is a continuation application of U.S. patent application Ser. No. 16/948,318, filed Sep. 14, 2020, and titled "Biased Passages For Turbomachinery", which application is a continuation application of U.S. patent application Ser. No. 15/103,252, filed Jun. 9, 2016, and titled "Biased Passages For Turbomachinery", now U.S. Pat. No. 10,774,842, which application is a 371 of International Application No. PCT/US16/30184, filed on Apr. 29, 2016, and titled "Biased Passages For Turbomachinery", which application claims the benefit of priority of U.S. Provisional Patent Application Ser. No. 62/155,341, filed Apr. 30, 2015, and titled "Biased Passage(s) Flow Devices For Turbomachinery" and U.S. Provisional Patent Application Ser. No. 62/243,415, filed Oct. 19, 2015, and titled "Methods For Designing Turbomachines To Account For Non-Uniform Pressures At Diffuser Inlet And Associated Structures And Devices". Each of these applications is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

The present invention generally relates to the field of turbomachinery. In particular, the present invention is directed to biased passages for turbomachinery.

BACKGROUND

A wide variety of diffuser types for centrifugal pump and compressor stages have been employed over the past several decades. In some cases, a good impeller has been designed first, and then a good diffuser is designed next, or the two elements are designed concurrently. Regardless, essentially all past work has been based on the quasi-steady/axisymmetric assumption of diffuser inlet flow which has typically been treated simply as a one-dimensional (1D) velocity triangle model for preliminary design. Much of these assumptions carry over even with computational fluid dynamic (CFD) models used today. It has typically been assumed, at some level, that the flow leaving an impeller, regardless of the number of blades, and then entering the diffuser, again regardless of the number of vanes, is essentially periodic and axisymmetric, and completely and uniformly fills each diffuser passage.

SUMMARY OF THE DISCLOSURE

In one implementation, the present disclosure is directed to a diffuser. The diffuser includes an inlet, a hub, and a shroud; and a row of vanes including a plurality of vane groupings each including a plurality of first partial height vanes affixed to one of the hub and the shroud, and a plurality second partial height vanes circumferentially spaced from the first partial height vane and affixed to the other of the hub and the shroud; wherein adjacent ones of the first and second partial height vanes overlap in a spanwise direction when viewed from a direction perpendicular to the spanwise direction, the spanwise direction being a direction extending between the hub and the shroud.

BRIEF DESCRIPTION OF THE DRAWINGS

For the purpose of illustrating the invention, the drawings show aspects of one or more embodiments of the invention.

However, it should be understood that the present invention is not limited to the precise arrangements and instrumentalities shown in the drawings, wherein:

FIG. **1** shows circumferential static pressure measurements at impeller tip/diffuser inlet for a flat plate diffuser operably coupled to a centrifugal compressor impeller operating at 120,000 RPM;

FIG. **2** is a subset of the data from FIG. **1**;

FIG. **3** shows circumferential static pressure measurements for the same machine as FIGS. **1** and **2**, but operating at 135,000 RPM;

FIG. **4** shows circumferential static pressure measurements for a channel diffuser operably coupled to a centrifugal compressor impeller operating at 100,000 RPM;

FIG. **5** shows circumferential static pressure measurements for the same machine as FIG. **4**, but operating at 135,000 RPM;

FIG. **6** shows a prior art volute;

FIG. **7** shows circumferential pressure measurements for a compressor or pump with a downstream volute;

FIG. **8** shows a flat plate diffuser with a biased passage formed by a partial height vane affixed to a shroud surface;

FIG. **9** shows a flat plate diffuser with a biased passage formed by a partial height vane affixed to a hub surface;

FIG. **10** shows a flat plate diffuser with a biased passage formed by a second vane having an alternate flowwise location and stagger angle;

FIG. **11** shows a flat plate diffuser with a biased passage formed by a second vane having an alternate thickness;

FIG. **12** shows a flat plate diffuser with a biased passage formed by a second vane having an alternate thickness;

FIG. **13** shows a flat plate diffuser with a biased passage formed by a second vane having an alternate chord length;

FIG. **14** shows a flat plate diffuser with a biased passage formed by a second vane having an alternate chord length and stagger angle;

FIG. **15** shows a flat plate diffuser with a biased passage formed by a second vane having an alternate pitch;

FIG. **16** shows a flat plate diffuser with a biased passage formed by second vanes having alternate chord length and thickness;

FIG. **17** shows a flat plate diffuser having a row of vanes that include first and second vanes, the second vanes having an alternate chord length;

FIG. **18** shows a flat plate diffuser having a row of vanes that include first and second vanes, the second vanes having an alternate chord length and leading edge location;

FIG. **19** shows a flat plate diffuser having a row of vanes that include first and second vanes, the second vanes having an alternate stagger angle;

FIG. **20** shows a flat plate diffuser having a row of vanes that include first and second vanes, the first vanes having an alternate stagger angle;

FIG. **21** shows a prior art channel diffuser;

FIG. **22** shows a channel diffuser having first and second vanes, the second vanes being flat plate vanes;

FIG. **23** shows a channel diffuser having first and second vanes, the second vanes being flat plate vanes;

FIG. **24** shows a channel diffuser with a biased passage formed by a second vane having alternate wedge angle;

FIG. **25** shows a channel diffuser with a biased passage formed by a second vane having alternate wedge angle;

FIG. **26** shows a channel diffuser with a biased passage formed by a second vane having alternate chord length;

FIG. **27** shows a channel diffuser with a biased passage formed by a second vane having alternate stagger angle;

FIG. **28** shows a channel diffuser with a biased passage formed by a second vane having alternate pitch;

FIG. **29** shows a channel diffuser with a biased passage formed by second vanes having alternate chord length and wedge angle;

FIG. **30** shows a channel diffuser having a row of vanes that include first and second vanes, the second vanes having an alternate chord length;

FIG. **31** shows a channel diffuser having a row of vanes that include first and second vanes, the second vanes having an alternate chord length and leading edge location;

FIG. **32** shows a channel diffuser having a row of vanes that include first and second vanes, the first vanes having an alternate stagger angle;

FIG. **33** shows a channel diffuser having a row of vanes that include first and second vanes, the second vanes having an alternate stagger angle;

FIG. **34** shows a turbomachine having a diffuser and a shroud with flowwise grooves;

FIG. **35** is another view of the diffuser and shroud of FIG. **34**;

FIG. **36** is another view of the diffuser and shroud of FIGS. **34** and **35**;

FIG. **37** shows a turbomachine having a diffuser and a shroud with flowwise grooves;

FIG. **38** is another view of the diffuser and shroud of FIG. **37**;

FIG. **39** is another view of the diffuser and shroud of FIGS. **37** and **38**;

FIG. **40** shows a turbomachine having a diffuser and a shroud with flowwise grooves in the hub and shroud;

FIG. **41** is another view of the diffuser and shroud of FIG. **40**;

FIG. **42** is another view of the diffuser and shroud of FIGS. **40** and **41**;

FIG. **43** shows the hub and shroud of FIGS. **40-42** with the hub clocked relative to the shroud;

FIG. **44** is an elevation view of the clocked hub and shroud of FIG. **43**;

FIG. **45** shows a diffuser having a hub and shroud with flowwise recesses and one set of recesses having a different characteristic than the other recesses, resulting in a biased passage;

FIG. **46** is an elevation view of the diffuser of FIG. **45**;

FIG. **47** is a cross-sectional view of a diffuser passage, the cross section taken at a location downstream of a leading edge of the passage and showing recesses in the hub and shroud surfaces of the passage, thereby providing a biased passage;

FIG. **48** shows a turbomachine having a diffuser and a shroud with flowwise channels in the hub and shroud;

FIG. **49** is another view of the diffuser of FIG. **48**;

FIG. **50** shows a turbomachine having a diffuser with flowwise channels in the hub and shroud, one of the channels having a different characteristic than other ones of the channels, resulting in a biased passage;

FIG. **51** is an elevation view of the diffuser of FIG. **50**;

FIG. **52** shows a vaned diffuser having flowwise channels in a shroud surface, one of the channels being a biased passage; and

FIG. **53** is an elevation view of the diffuser of FIG. **52**.

DETAILED DESCRIPTION

Aspects of the present disclosure include turbomachines having one or more flow guiding features designed to increase the performance of the turbomachine. In some examples, flow guiding features are designed and configured to bias a circumferential pressure distribution at a diffuser inlet toward circumferential uniformity, or otherwise account for such low-frequency spatial pressure variations. In some examples, a diffuser having a row of vanes that include a plurality of first vanes and at least one second vane having a different characteristic than the first vanes are disclosed. In some examples, diffusers having an aperiodic section including one or more biased passages for biasing a flow field are disclosed. In some examples, turbomachines having flowwise elongate recesses in one or both of a hub and shroud surface are disclosed. As described herein, the present disclosure includes various combinations of flow guiding features that may be incorporated in a turbomachine to account for flow field characteristics, including but not limited to circumferential asymmetries, to thereby improve the performance of the turbomachine.

FIGS. **1-5** are graphs of static pressure versus circumferential angle for various diffuser types and operating conditions, each of the diffusers operably arranged downstream of a centrifugal compressor. Each of FIGS. **1-5** shows time-averaged static pressure at several circumferential locations around the machines, all at a streamwise location between impeller exit and diffuser inlet. FIG. **1** shows time averaged static pressures for various flowrates **102-116**, with curve **104** being the lowest flow rate and **102** the highest, all at the same impeller rotational speed, here 120,000 RPM. The data in FIG. **1** is from a flat plate diffuser having 14 vanes. Vane location lines **118** show the approximate location of each of the vanes with respect to the static pressure measurements. As shown in FIG. **1**, each of pressure curves **102-116** has a sawtooth pattern, with peaks corresponding to each vane location **118**, such sawtooth pattern being mostly due to the natural vane-to-vane pressure field that exists in vaned diffusers or any cascade of turbomachinery vanes. Thus, the pressure curves **102-116** have a first spatial frequency that is substantially the same as the spatial frequency of the vanes of the flat plate diffuser. Pressure curves **102-116**, however, also have a lower-frequency wave type variation superposed on the sawtooth shape, the lower-frequency wave having a primary spatial frequency that is less than the spatial frequency of the vanes. FIG. **2** shows a subset of the pressure curves from FIG. **1**—curves **102**, **104**, and **112**. FIG. **2** also includes mean pressure curves **202**, **204**, and **206**, which, in this example, are 6^{th} order polynomial curves. The low-frequency spatial variation in time-averaged circumferential static pressure can be seen in the mean pressure curves **202**, **204**, and **206**, in this example, each flow rate resulting in a low-frequency pressure variation with two maxima and two minima around the circumference of the machine.

FIGS. **1** and **2** indicate that, contrary to the common assumption made in turbomachinery design that the time averaged circumferential flow and pressure distribution at the diffuser inlet is substantially axisymmetric, the static pressure in fact varies around the circumference of the machine. In regions where the pressure is high, the velocities may be generally low and vane incidence may be closer to one extreme, e.g., low or high, depending, for example, on phase angle. And in regions where the pressure is low, the velocities may be generally high and vane incidence may be closer to the other extreme, e.g., high or low. Consequently, in regions where the incidence at the diffuser inlet due to this distortion is high, early stall may be more likely and losses may be relatively high. The flow field in these cases may be developing high flow and low flow regions with different pressures in order to pass the asymmetric impeller flow into a fixed number of diffuser passages.

FIG. **3** shows static pressure test data at three flow rates **302**, **304**, **306** with the same flat plate diffuser as FIGS. **1** and **2**, but with the compressor operating at a different speed, here 135,000 RPM, with curve **304** being the lowest flow rate and **302** the highest. Mean pressure curves **308**, **310**, and **312** show a similar low-frequency variation as shown in FIG. **2**, and also shows a circumferential shift in local maxima and minima as flow rates decrease and the system approaches surge.

FIGS. **4** and **5** similarly show a time-averaged circumferential distribution of static pressure at diffuser inlet for a double-divergence channel diffuser operably coupled to a centrifugal compressor impeller operating at 100,000 RPM (FIG. **4**) and 135,000 RPM (FIG. **5**). In FIG. **4**, pressure curves **402** and **404** and mean pressure curves **408**, **410** show a low-frequency circumferential variation having a primary spatial frequency distribution that is less than the spatial frequency distribution of the diffuser channels, as indicated by vane locations **406**. Unlike FIGS. **1-3**, pressure curves **402** and **404** do not have the same number of higher-frequency local maxima in the sawtooth pattern as the number of vanes at locations **406**. Instead, a pocket **412** exists in the data, which shifts with flow rate. Pocket **412** suggests an offset or relief process may be occurring to allow the non-uniform flow to enter the fixed diffuser passages, and indicates potential underperforming diffuser passages, at least in the region of pocket **412**. FIG. **5** includes pressure curves **502**, **504**, **506**, and **508** and mean pressure curves **512**, **514**, **516**, and **518** corresponding to four different flow rates, all at 135,000 RPM. As in FIG. **4**, pockets **510** appear at each flowrate.

Extensive testing and analysis of circumferential pressure data for various diffuser types have shown that the low-frequency circumferential pressure distribution shown in FIGS. **1-5** do not originate from an asymmetric flow path located upstream or downstream of the diffuser. FIG. **6** shows an example of an asymmetric flow path in the form of a volute **600** located downstream of diffuser **602**. It is well known that volutes such as volute **600** create an asymmetry in the flow field of a diffuser, such as diffuser **602**, proximate cutwater **604**, (also referred to as a volute tongue **604**) e.g., creating a volute distortion zone **606** extending between locations A and B. In the illustrated example, volute distortion zone extends from approximately 90 degrees upstream of cutwater **604** (location "A") to approximately 45 degrees downstream of the cutwater (location "B"). FIG. **7** shows circumferential pressure versus flow rate for a compressor or pump having a volute. As shown in FIG. **7**, the volute creates strong circumferential distortions in impeller exit pressures at low flows due to strong diffusion in the volute at that condition, which diminishes as flow rate increases and the volute flow state switches from diffusion to acceleration. Pressure curves 1 and 2 in FIG. **7** are in volute distortion zone **606** (FIG. **6**).

Various diffuser designs have been developed to improve diffuser performance in machines with asymmetric flow paths such as volutes that try to account for the large circumferential distortions caused by the volute or other asymmetric flow path. Other examples of such asymmetric flow paths located upstream or downstream of the diffuser include a side inlet in front of the impeller, an asymmetric collector, etc. Rather than localized bulk pressure distortions caused by an asymmetric flow path such as a volute, the low frequency pressure variations shown in FIGS. **1-5** extend around the entire circumference of the machine, are an active phenomena that shift in location with operating condition, and exist whether or not asymmetric flow paths are present. The present paper discloses a variety of diffusers having biased passages designed and configured to improve diffuser performance in light of these low-frequency spatial pressure variations. In some embodiments, biased passages are provided that are located, configured, and dimensioned to bias a low-frequency circumferential pressure distribution at a diffuser inlet, such as the low-frequency variations shown in FIGS. **1-5**, toward circumferential uniformity. In other examples, biased passages are designed and configured to also, or alternatively, improve the performance of a turbomachine, including increasing the controllability of spatial flow field variations, modifying flow field variations, and improving the performance of the turbomachinery in light of flow field variations.

The present paper includes a variety of diffuser design variables or characteristics that may be combined in any number of different combinations to develop a diffuser with biased passages tailored for particular performance and flow fields. Non-limiting examples of such diffuser design variables or characteristics include, but are not limited to, vane leading edge location, vane trailing edge location, a radial distance of a vane from a diffuser centerline, vane chord length, a maximum thickness of a vane, a vane height, a vane flowwise shape distribution, a vane stagger angle, vane wedge angle, channel divergence angle, vane pitch, vane lean, vane twist, vane leading edge shape, e.g., leading edge chevron, swallowtail or scallop, etc., fixed or moveable vanes, a passage height between hub and shroud surfaces, a circumferential location of a biased passage, a number of biased passages, and one or more flowwise channels located in one or both of hub and shroud surfaces extending upstream and/or downstream of a diffuser passage. One or more diffuser design variables may be adjusted for a subset of vanes in a diffuser vane row to create one or more biased passages having a cross-sectional flow area distribution in a flowwise direction that is different than a cross-sectional flow area distribution of a plurality of other diffuser passages in the same vane row. Such diffuser design variable combinations may be applied to any type of diffuser, including, for example, any type of vaned diffuser, including flat plate, airfoil, straight channel, conical, single row or tandem, single or multiple vane type per row, and any solidity, and may also be applied to vaneless diffusers.

In yet other examples, diffusers made in accordance with the present disclosure include multi-vane groupings, wherein each vane grouping includes two or more vanes each having one or more different characteristics than other ones of the vanes in the grouping. The groupings may be arranged in a periodic arrangement around the circumference of the machine, or may be arranged in an aperiodic arrangement, thereby resulting in one or more biased passages. Diffusers made in accordance with the present disclosure may include any combination of vane groupings disclosed herein and biased passages disclosed herein. For example, a diffuser may include a periodic section of one or more vane groupings, and one or more aperiodic sections including one or more biased passages. The one or more characteristics that may vary among vanes in a vane grouping may include, but are not limited to, vane leading edge location, vane trailing edge location, a radial distance of a vane from a diffuser centerline, vane chord length, a maximum thickness of a vane, a vane height, a vane flowwise shape distribution, a vane stagger angle, vane wedge angle, channel divergence angle, vane pitch, vane lean, vane twist, vane leading edge shape, e.g., leading edge chevron, swallowtail or scallop, etc., fixed or moveable vanes, and a passage height between hub and shroud surfaces. One or more of such characteristics may be varied. Such groupings may be designed, configured, and located to improve the performance of a turbomachine, including increasing the controllability of spatial flow field variations, modifying flow field variations, and improving the performance of the turbomachinery in light of flow field variations, such as the circumferential pressure variations discussed above.

Examples of vaneless diffusers with biased passages include vaneless diffusers with flowwise recesses, e.g., channels, grooves, or other recesses located in the hub or shroud surface for varying a passage height in one or more circumferential locations. As described more below, elongate recesses include, but are not limited to, flowwise channels having substantially square edges and flowwise grooves having rounded edges. In some examples, vaneless diffusers may have an aperiodic arrangement of flowwise recesses. The flowwise length of such recesses may vary, from longer recesses extending upstream of the diffuser into the impeller and downstream of the diffuser, to shorter recesses located at any flowwise location in the diffuser and of any shorter length. Biased passages disclosed herein may have a cross-sectional area that is greater than a cross-sectional area of other passages in a diffuser row. Such increased flow area passage(s) may provide a biased relief passage that may be designed and configured to accept an asymmetric portion of an impeller exit flow and cause a more uniform distribution of flow into other non-biased passages. In other examples, biased passages disclosed herein may have a reduced cross-sectional area as compared to the cross-sectional area of other non-biased passages, including fully blocked passages. Thus, as used herein, a reduced area biased passage includes fully blocked passages, or the absence of a diffuser passage in a location where a passage would be for a fully periodic diffuser passage arrangement. Such decreased flow area biased passages may be designed and configured to redistribute or otherwise influence an asymmetric impeller exit flow field, thereby providing a more uniform distribution of flow in the non-biased passages.

The present disclosure also includes experimental and computational methods of designing flow structures for turbomachines to improve performance. In one example, a computational model of a turbomachine and/or diffuser may be developed. A circumferential pressure distribution may be calculated at one or more operating conditions and the performance of the diffuser may be analyzed. In some cases, a low-frequency circumferential variation in pressure will be calculated at the diffuser inlet. The computational model of the diffuser may be iteratively adjusted with the addition of one or more biased passages, and a circumferential pressure distribution and diffuser performance may be calculated for each case to identify an optimized biased passage design. In other examples, rather than calculating a circumferential pressure distribution, a seeded perturbation in the diffuser inlet pressure or other equivalent approach may be applied to the computational model for various diffuser designs to determine an optimized biased passage arrangement. In yet other examples, experimental methods of determining biased passage designs may be implemented, including instrumenting a testing platform with sufficient pressure measurements around the circumference of a diffuser inlet to fully characterize the primary components of any circumferential pressure variation. The circumferential pressure variation for various diffuser designs with and without biased passages may be measured and improved biased passage designs determined.

FIGS. **8-20** illustrate exemplary embodiments of vaned diffusers having one or more biased passages. FIG. **8** shows a portion of an exemplary vaned flat plate low solidity diffuser **800** that has a row of vanes **802** extending between a hub **804** and shroud **806** and extending in a flowwise direction between a diffuser inlet **808** and exit **810**. Row **802** includes a plurality of first vanes **812** and at least one second vane **814**. Although only three are shown, first vanes **812** are equally spaced around one or more portions of diffuser **800**. As shown, second vane **814** has a different characteristic than first vanes **812**, here a different height, with second vane **814** being a partial height vane affixed to hub **804**. The partial height of second vane **814** results in a biased passage **816** that has a different cross-sectional area distribution in the flowwise direction than passage **816** between first vanes **812**. Thus, diffuser **800** has a plurality of passages located around a circumference of the diffuser, including at least one periodic section of passages **816** extending between first vanes **812**, wherein the section is periodic because the first vanes **812** are equally spaced at regular intervals around a diffuser centerline. Diffuser **800** also includes at least one aperiodic section including biased passage **818**, the section being aperiodic because there is a discontinuity in the periodic nature of first vanes **812**, here, biased passage **818** having a larger cross-sectional flow area than passages **816**. Exemplary diffuser **800** is designed and configured for receiving a flow field having a circumferential pressure distribution and biased passage **816** is located, configured, and dimensioned to bias the circumferential pressure distribution toward circumferential uniformity, e.g., bias a low-frequency spatial pressure variation, such as the ones shown in FIGS. **1-5**. Biased passage may also be located, configured, and dimensioned to improve the performance of a turbomachine, including increasing the controllability of spatial flow field variations, modifying flow field variations, and improving the performance of the turbomachinery in light of flow field variations. Diffuser **800** may have one or more of biased passages **816** located at any location around the circumference of the diffuser. FIG. **9** shows a diffuser **900** that is substantially the same as diffuser **800**, including first vanes **902** extending between hub **904** and shroud **906**, and at least one second vane **908**, wherein second vane is partial height and results in biased passage. Unlike diffuser **800**, second vane **908** is affixed to the shroud **906**, rather than hub **904**. Alternative embodiments may include combinations of second vanes **814** and **908**, e.g., a single diffuser with one or more partial-height vanes affixed to the shroud surface and one or more partial-height vanes affixed to the hub surface.

FIG. **10** shows an exemplary diffuser **1000** that has a plurality of first vanes **1002** and at least one second vane **1004** having a different characteristic, here radial distance from a centerline **1005** of diffuser **1000** and stagger angle, thereby forming biased passage **1006**. Broken line **1008** shows where one of first vanes **1002** would have been located if the periodic nature of first vanes had been continued, e.g., a periodic first vane location, as is the case with existing diffusers. Broken lines **1010** illustrate the stagger angle may be varied +/− from a first vane stagger angle. Although only a portion of diffuser **1000** is shown, the diffuser may include one or more biased passages **1006**. First and second vanes **1002**, **1004** may all be full height, or one or both may be partial height. As shown, exemplary second vane **1004** is slid back along a flowwise direction as compared to periodic first vane location **1008**, resulting in leading edge **1012** and trailing edge **1014** both being a greater radial distance from centerline **1005** than leading and trailing edges **1016**, **1018** of first vanes **1002**. Biased passage

1006 creates an aperiodic section in diffuser 1000 in the form of a larger cross-sectional flow area at inlet 1020 of diffuser 1000.

FIG. 11 shows an exemplary diffuser 1100 that has a plurality of first vanes 1102 and at least one second vane 1104 having a different characteristic, here thickness, thereby forming biased passages 1106. Although only a portion of diffuser 1100 is shown, the diffuser may include two or more biased passages 1106. First and second vanes 1102, 1104 may all be full height, or one or both may be partial height. As shown, exemplary second vane 1104 is thinner than first vanes 1102, resulting in biased passages 1106 that have a different cross-sectional area distribution than passages 1108, creating an aperiodic section in diffuser 1100 in the form of a larger cross-sectional flow area adjacent second vane 1104.

FIG. 12 shows an exemplary diffuser 1200, which is similar to diffuser 1100 (FIG. 11) and has a plurality of first vanes 1202 and at least one second vane 1204 having a different characteristic, here maximum thickness, thereby forming biased passages 1206. Although only a portion of diffuser 1200 is shown, the diffuser may include two or more biased passages 1206. First and second vanes 1202, 1204 may all be full height, or one or both may be partial height. As shown, exemplary second vane 1204 is thicker than first vanes 1202, resulting in biased passages 1206 that have a different cross-sectional area distribution than passages 1208, creating an aperiodic section in diffuser 1200 in the form of a smaller cross-sectional flow area adjacent second vane 1204.

FIG. 13 shows an exemplary diffuser 1300, which is similar to diffusers 1100 and 1200 (FIGS. 11 and 12) and has a plurality of first vanes 1302 and at least one second vane 1304 having a different characteristic, here chord length, thereby forming biased passages 1306. Although only a portion of diffuser 1300 is shown, the diffuser may include two or more biased passages 1306. First and second vanes 1302, 1304 may all be full height, or one or both may be partial height. As shown, exemplary second vane 1304 is longer than first vanes 1302, resulting in biased passages 1306 that have a different flowwise cross-sectional area distribution than passages 1308, creating an aperiodic section in diffuser 1300 proximate second vane 1304. FIG. 14 shows diffuser 1400, which is substantially the same as diffuser 1300 with equivalent components having the same name and same reference numeral suffix. Unlike diffuser 1300, second vane 1404 may have a different stagger angle than first vanes 1402, as indicated by broken line 1410, showing one possible alternative stagger angle. The particular stagger angle of second vane 1404 may be varied, including both positive and negative angles with respect to the first vane 1402 stagger angle.

FIG. 15 shows an exemplary diffuser 1500, which is similar to diffusers 1100-1400 (FIGS. 11-14) and has a plurality of first vanes 1502 and at least one second vane 1504 having a different characteristic, here pitch, resulting in a different circumferential spacing between second vane 1504 and adjacent vanes than the spacing between adjacent first vanes 1502, thereby forming biased passages 1506*a* and 1506*b*. Biased passage 1506*a* has a smaller cross-sectional area and 1506*b* has a larger cross-sectional area than passages 1508. Although only a portion of diffuser 1500 is shown, the diffuser may include two or more biased passages 1506*a, b*. First and second vanes 1502, 1504 may all be full height, or one or both may be partial height. As shown, exemplary second vane 1504 has the same pitch, shape, and chord length as first vanes 1202, but is located at a different circumferential location than a periodic first vane location, resulting in an aperiodic section and diffuser 1500 having a non-uniform and aperiodic circumferential vane pitch distribution.

FIG. 16 shows exemplary diffuser 1600, which has a plurality of first vanes 1602 (only two of twelve labeled) and two second vanes 1604*a*, 1604*b* each having a different characteristic, here maximum thickness and chord length, than the first vanes, resulting in biased passages 1606*a* and 1606*b*. Second vane 1604*a* has the same thickness as the first vanes 1602, but a longer chord length, resulting in biased passages 1606*a* having a different flowwise cross-sectional area distribution than passages 1608. Second vane 1604*b* has a greater thickness than first vanes 1602, resulting in biased passages 1606*b* having a different flowwise cross-sectional area distribution, including a smaller cross-sectional area, than passages 1608. First and second vanes 1602, 1604*a*, 1604*b* may all be full height, or one or more may be partial height. As shown, second vanes 1604*a*, 1604*b* and associated biased passages 1606*a*, 1606*b* are spaced approximately 180 degrees around the circumference of diffuser 1600. First vanes 1602 are equally spaced from adjacent first vanes, providing two periodic sections 1610 and second vanes 1604*a*, 1604*b* result in two aperiodic sections 1612.

FIG. 17 shows exemplary diffuser 1700, which has a plurality of first vanes 1702 (only two of seven labeled) and a plurality of second vanes 1704 (only two of seven labeled), each having a different characteristic from first vanes 1702, here chord length. Unlike diffuser 1600, diffuser 1700 has an equal number of first vanes 1702 and second vanes 1704 and a fully periodic arrangement of passages 1706*a*, 1706*b*. First vanes 1702 and second vanes 1704 may all be full height, or one or more may be partial height. First and second vanes 1702, 1704 are arranged in vane groupings, here two vanes per grouping, where diffuser 1700 has a periodic arrangement of multi-vane groupings, and wherein each vane grouping includes first and second vanes 1702, 1704, each having a different characteristic than other ones of the vanes in the grouping. FIG. 18 shows diffuser 1800, which is substantially the same as diffuser 1700, including a plurality of first vanes 1802 (only two of seven labeled) and a plurality of second vanes 1804 (only two of seven labeled), each having a different characteristic from first vanes 1802, here chord length. Unlike diffuser 1700, each of second vanes 1804 also have a different flowwise location than first vanes 1802, with a location of leading edge 1812 being at a different radial distance, here a greater distance, from diffuser centerline 1814, than a radial distance of first vane leading edges 1816 from the diffuser centerline. For example, each of second vanes 1804 are slid back in a flowwise direction as compared to a periodic first vane location. As with diffuser 1700, diffuser 1800 includes first and second vanes 1802, 1804 that are arranged in multi-vane groupings, here two vanes per grouping, where diffuser 1800 has a periodic arrangement of multi-vane groupings. In other examples, one or more characteristics of one or more of first and/or second vanes 1702, 1802, 1704, 1804 may be varied to create one or more aperiodic sections having biased passages that are configured to address asymmetric pressure fields, for example, the asymmetric pressure fields shown in FIGS. 1-5. The one or more characteristics may include, for example, any of the characteristics described herein, such as vane height, stagger angle, pitch, vane shape, vane leading and trailing edge location, and chord length, etc.

FIG. 19 shows exemplary diffuser 1900, which has a plurality of first vanes 1902 (only two of seven labeled) and a plurality of second vanes **1904** (only two of seven labeled), each having a different characteristic from first vanes **1902**, here chord length and stagger angle. Diffuser **1900** has an equal number of first vanes **1902** and second vanes **1904** and when second vanes **1904** are all at the same stagger angle, a fully periodic arrangement of passages **1906***a*, **1906***b*. First vanes **1902** and second vanes **1904** may all be full height, or one or more may be partial height. First and second vanes **1902**, **1904** are arranged in vane groupings, here two vanes per grouping, where diffuser **1900** has a periodic arrangement of multi-vane groupings. As indicated by broken lines **1910**, the stagger angle of second vanes **1904** may be the same as first vanes **1902**, or may be varied in a positive or negative direction from the first vane stagger angle. In some embodiments, the stagger angle of the second vanes **1904** may be varied, and may be arranged to form an aperiodic arrangement with one or more biased passages. For example, all but one of the second vanes **1904** may have the same stagger angle as first vanes **1902**, with one of the second vanes having an alternate stagger angle, thereby providing two biased passages on either side of the altered-angle full height second vane. In other examples, the stagger angle of other numbers of second vanes **1904** may be varied.

FIG. **20** shows exemplary diffuser **2000**, which is substantially the same as diffuser **1900** with equivalent components having the same name and same reference numeral suffix. Unlike diffuser **1900**, where the stagger angle of second vanes **1904** may be varied, in diffuser **2000**, the stagger angle of first vanes **2002** may be varied, as indicated by broken lines **2010**. As with diffuser **1900**, the stagger angle of less than all of first vanes **2002** may be different than other ones of the first vanes, thereby resulting in an aperiodic arrangement and one or more biased passages. First and second vanes **2002**, **2004** are arranged in vane groupings, here two vanes per grouping, where diffuser **2000** has a periodic arrangement of multi-vane groupings. In other examples, characteristics of diffusers **1900** and **2000** may be combined, including varying the stagger angle of select ones of both the first and second vanes, or the stagger angle of a subset of first vanes **1902**, **2002**, or a subset of second vanes **1904**, **2004**.

In another embodiment, an exemplary diffuser may include a plurality of vane groupings, wherein each vane in the grouping has a different height. For example, a vane grouping may include two partial-height vanes, including a first partial height vane affixed to a hub or shroud surface and a second, adjacent partial height vane affixed to the hub or shroud surface. The diffuser may include a periodic arrangement of such groupings, e.g., in one example the first and second partial height vanes may all be equally spaced around the circumference of the machine. In one example, the first partial height vane may have a different height than the second partial height vane. For example, the first partial height vane may have a height between approximately 15% and approximately 65% of a passage height, and in some examples, approximately 50% of the passage height. The second partial height vane may have a height between approximately 5% and approximately 45% of the passage height, and in some examples, approximately 15%. In one example, the first and second partial height vanes in each vane grouping may be affixed to opposite sides of the passage, e.g., the first partial height vane may be affixed to the shroud and the second partial height vane may be affixed to the hub. Such partial-height vane groupings may reduce leading edge metal blockage and increase passage area, and allow for flow reorganization especially near choke, thereby improving performance. In yet other examples, vane groupings may include three or more vanes, such vane groupings repeated around the perimeter of the diffuser. In yet other examples, one or more biased passages may be formed by locating such vane groupings adjacent periodic sections. For example, in a diffuser with 14 vanes, a two vane grouping with first and second partial height vanes may be used in the place of 2 to 12 of the 14 vanes in one or more circumferential locations resulting in one or more biased passages.

FIG. **21** shows a prior art channel-type diffuser **2100** and FIGS. **22-33** show exemplary embodiments of channel-type diffusers made in accordance with the present disclosure. As shown in FIG. **21**, prior art channel-type diffuser **2100** includes a plurality of vanes **2102** (only one labeled) defining passages **2104** (only one labeled) in the form of channels. Diffuser **2100** is similar to the diffuser used to generate the test data shown in FIGS. **4** and **5**. Diffuser **2100** is fully periodic and symmetric, with each of vanes **2102** having the same stagger angle S and wedge angle W, and each passage **2104** having the same divergence angle D.

FIG. **22** shows an exemplary channel diffuser **2200** having a plurality of passages **2202** (only one labeled) extending between a first vane **2204** (only one labeled). Unlike prior art diffuser **2100**, however, each passage **2202** also includes a second vane **2206** located between adjacent first vanes **2204**. Exemplary second vanes **2206** are flat plates, each have a leading edge **2208** that is downstream from diffuser inlet **2210**, and a trailing edge **2212** that is positioned upstream of diffuser exit **2214**. Second vanes **2206** are full height. In other examples, one or more of first and/or second vanes **2204**, **2206** may be partial height. In the illustrated example, second vanes **2206** have a shorter chord length than a length of passages **2202**, and are substantially centered in the passages in both circumferential and flowwise directions. First and second vanes **2204**, **2206** are arranged in vane groupings, here two vanes per grouping, where diffuser **2200** has a periodic arrangement of multi-vane groupings. Exemplary passages **2202** are periodic, however, one or more characteristics of one or more of first vanes **2204** and/or second vanes **2206** may be varied to create one or more biased passages. One or more characteristics of one or more of first and/or second vanes **2204**, **2206** may be varied to create one or more aperiodic sections having biased passages that are configured to address asymmetric pressure fields, for example, the asymmetric pressure fields shown in FIGS. **1-5**. The one or more characteristics may include, for example, any of the characteristics described herein, such as vane height, stagger angle, pitch, vane shape, vane leading and trailing edge location, and chord length, etc. For example, second vanes **2206** may be of any type including airfoil type and need not all be centered in passages **2202**; at least one may be relocated or resized to create a biased passage including partial height design.

FIG. **23** shows an exemplary channel diffuser **2300**, which is similar to channel diffuser **2200** with equivalent components having the same name and same reference numeral suffix. Diffuser **2300** includes a plurality of passages **2302** (only one labeled) extending between first vanes **2304** (only one labeled). Each passage **2302** also includes a second vane **2306** located between adjacent first vanes **2304**. Exemplary second vanes **2306** are flat plates. As compared to second vanes **2206** (FIG. **22**), second vanes **2306** are narrower and positioned farther upstream, in this example with leading edge **2308** located at diffuser inlet **2310**, and trailing edge **2312** located farther upstream of diffuser exit **2314**. Second vanes **2306** are full height. In other examples, one or more of first and/or second vanes **2304**, **2306** may be partial height. In the illustrated example, second vanes **2306** have a shorter chord length than a length of passages **2302**, and are substantially centered in the passages in a circumferential direction and located upstream of a passage **2302** midpoint in the flowwise direction. First and second vanes **2304**, **2306** are arranged in vane groupings, here two vanes per grouping, where diffuser **2300** has a periodic arrangement of multi-vane groupings. Exemplary passages **2302** are periodic, however, one or more characteristics of one or more of first vane **2304** and/or second vanes **2306** may be varied to create one or more biased passages. One or more characteristics of one or more of first and/or second vanes **2304**, **2306** may be varied to create one or more aperiodic sections having biased passages that are configured to address asymmetric pressure fields, for example, the asymmetric pressure fields shown in FIGS. **1**-**5**. The one or more characteristics may include, for example, any of the characteristics described herein, such as vane height, stagger angle, pitch, vane shape, vane leading and trailing edge location, and chord length, etc. For example, second vanes **2306** may be of any type including airfoil type and need not all be centered in passages **2302**; at least one may be relocated or resized to create a biased passage including partial height design.

FIG. **24** shows an exemplary channel diffuser **2400** that is the same as prior art diffuser **2100** (FIG. **21**) except that diffuser **2400** includes a plurality of first vanes **2402** and one second vane **2404** that has a characteristic that is different than first vanes **2402**, here, wedge angle. In the illustrated example, diffuser **2400** includes a single second vane **2404** located in a first vane **2402** periodic location, or where a first vane **2402** would have been located in a prior art arrangement. Second vane **2404** has a lower wedge angle W**2** than first vane **2402** wedge angle W**1**. The smaller wedge angle W**2** of second vane **2404** results in two biased passages **2406**. Diffuser **2400** includes a periodic section **2408** of first vanes **2402** and associated passages **2410** and an aperiodic section **2412** including the two biased passages **2406**. In other examples, one or more additional first vanes **2402** may be replaced with second vanes **2404** that may have one or more characteristics that are different than first vanes **2402**, thereby creating one or more additional biased passages.

FIG. **25** shows an exemplary channel diffuser **2500** that is similar to diffuser **2400** (FIG. **24**) with equivalent components having the same name and same reference numeral suffix. Diffuser **2500** includes a plurality of first vanes **2502** and one second vane **2504** that has a characteristic that is different than first vanes **2502**, here, wedge angle. Unlike diffuser **2400**, second vane **2504** has a larger wedge angle than first vanes **2502**. In the illustrated example, diffuser **2500** includes a single second vane **2504** located in a first vane **2502** periodic location, or where a first vane **2502** would have been located in a prior art arrangement. Second vane **2504** has a larger wedge angle W**2** than first vane **2502** wedge angle W**1**. The larger wedge angle W**2** of second vane **2404** results in two biased passages **2506** that have a smaller cross-sectional area than passages **2510**. Diffuser **2500** includes a periodic section **2508** of first vanes **2502** and associated passages **2510** and an aperiodic section **2512** including the two biased passages **2506**. In other examples, one or more additional first vanes **2502** may be replaced with second vanes **2504** that may have one or more characteristics that are different than first vane **2502**, thereby creating one or more additional biased passages.

FIG. **26** shows an exemplary channel diffuser **2600** that is similar to diffusers **2400** (FIG. **24**) and **2500** (FIG. **25**) with equivalent components having the same name and same reference numeral suffix. Diffuser **2600** includes a plurality of first vanes **2602** and one second vane **2604** that has a characteristic that is different than first vane **2602**, here, chord length. In the illustrated example, diffuser **2600** includes a single second vane **2604** located in a first vane **2602** periodic location, or where a first vane **2602** would have been located in a prior art arrangement. The longer length of second vane **2604** results in two biased passages **2606** that have a different flowwise cross-sectional area distribution than passages **2610**, and result in the trailing edge of second vane **2604** acting as an additional flow guide at diffuser exit to reduce losses at the diffuser exit. Diffuser **2600** includes a periodic section **2608** of first vanes **2602** and associated passages **2610** and an aperiodic section **2612** including the two biased passages **2606**. In other examples, one or more additional first vanes **2602** may be replaced with second vanes **2604** that may have one or more characteristics that are different than first vanes **2602**, thereby creating one or more additional biased passages.

FIG. **27** shows an exemplary channel diffuser **2700** that is similar to diffusers **2400** (FIG. **24**), **2500** (FIG. **25**), and **2600** (FIG. **26**) with equivalent components having the same name and same reference numeral suffix. Diffuser **2700** includes a plurality of first vanes **2702** and one second vane **2704** that has a characteristic that is different than first vane **2702**, here, vane stagger angle, resulting in alternate passage divergence angles. In the illustrated example, diffuser **2700** includes a single second vane **2704** located approximately where a first vane **2702** would have been located in a prior art arrangement. As indicated by the broken lines, the stagger angle of second vane **2704** may be varied in a +/− direction relative to the stagger angle of first vanes **2702**, resulting in two biased passages **2706** that have a different flowwise cross-sectional area distribution than passages **2710**. Diffuser **2700** includes a periodic section **2708** of first vanes **2702** and associated passages **2710** and an aperiodic section **2712** including the two biased passages **2706**. In other examples, one or more additional first vanes **2702** may be replaced with second vanes **2704** that may have one or more characteristics that are different than first vanes **2702**, thereby creating one or more additional biased passages.

FIG. **28** shows an exemplary channel diffuser **2800** that is similar to diffusers **2400** (FIG. **24**), **2500** (FIG. **25**), **2600** (FIG. **26**), and **2700** (FIG. **27**) with equivalent components having the same name and same reference numeral suffix. Diffuser **2800** includes a plurality of first vanes **2802** and one second vane **2804** that has a characteristic that is different than first vane **2802**, here, vane pitch, thereby altering vane circumferential location and spacing. In the illustrated example, diffuser **2800** includes a single second vane **2804** in the place of one of first vane **2802**. As shown, the pitch of second vane **2804** is different than the pitch of first vanes **2802**, resulting in two biased passages **2806***a*, **2806***b* that have different flowwise cross-sectional area distributions than passages **2810**. Diffuser **2800** includes a periodic section **2808** of first vanes **2802** and associated passages **2810** and an aperiodic section **2812** including the two biased passages **2806***a*, **2806***b*. In other examples, one or more additional first vanes **2802** may be replaced with second vanes **2804** that may have one or more characteristics that are different than first vane **2802**, thereby creating one or more additional biased passages.

FIG. **29** shows an exemplary diffuser **2900**, which combines the characteristics of diffusers **2500** (FIG. **25**) and **2600** (FIG. **26**). As shown, diffuser **2900** includes a plurality of first vanes **2902** and two second vanes **2904***a*, **2904***b* that each have a characteristic that is different than first vanes **2902**. Second vane **2904***a* has a greater chord length than first vanes **2902** and second vane **2904***b* has a greater wedge angle W**2** than wedge angle W**1** of first vanes **2902**, resulting in biased passages **2906***a* and **2906***b* that have different flowwise cross-sectional area distributions than passages **2910**. Diffuser **2900** includes periodic sections **2908***a*, **2908***b* of first vanes **2902** and associated passages **2910** and aperiodic sections **2912***a*, **2912***b* including biased passages **2906***a*, **2906***b*, respectively. In other examples, one or more additional first vanes **2902** may be replaced with second vanes **2904** that may have one or more characteristics that are different than first vanes **2902**, thereby creating one or more additional biased passages.

FIG. **30** shows an exemplary channel diffuser **3000** which has a plurality of first vanes **3002** (only one labeled) and a plurality of second vanes **3004** (only one labeled), each of the second vanes having a different characteristic from first vanes **3002**, here chord length. Diffuser **3000** has an equal number of first vanes **3002** and second vanes **3004** and a fully periodic arrangement of passages **3006***a*, **3006***b*. As with any of the channel diffusers disclosed herein, first vanes **3002** and second vanes **3004** may all be full height, or one or more may be partial height. FIG. **31** shows diffuser **3100**, which is similar to diffuser **3000**, including a plurality of first vanes **3102** (only one labeled) and a plurality of second vanes **3104** (only one labeled), each of the second vanes having a different characteristic from first vanes **3102**, here chord length and flowwise location. Each of second vanes **3104** have a different flowwise location than first vanes **3102**, with a location of leading edge **3112** being at a different radial distance, here a greater distance, from diffuser centerline **3114**, than a radial distance of first vane leading edges **3116** from the diffuser centerline. For example, each of second vanes **3104** are slid back in a flowwise direction as compared to a periodic first vane location. One or more characteristics of one or more of first and/or second vanes **3002**, **3102**, **3004**, **3104** may be varied to create one or more aperiodic sections having biased passages that are configured to address asymmetric pressure fields, for example, the asymmetric pressure fields shown in FIGS. **1-5**. The one or more characteristics may include, for example, any of the characteristics described herein, such as vane height, stagger angle, pitch, vane shape, vane leading and trailing edge location, and chord length, etc.

FIG. **32** shows an exemplary channel diffuser **3200** which is substantially the same as diffuser **3000** (FIG. **30**) with equivalent components having the same name and same reference numeral suffix. Unlike diffuser **3000**, where the wedge angle, vane stagger, and channel divergence angles of first and second vanes **3002**, **3004** are the same, the stagger angle of first vane **3202** and associated channel diverge angles of adjacent passages **3206** may be varied in either direction from a stagger angle of second vanes **3204**. In some examples, the stagger angle of less than all of first vanes **3202** may be different than other ones of the first vanes, thereby resulting in an aperiodic arrangement and one or more biased passages **3206**. FIG. **33** shows diffuser **3300**, which is substantially the same as diffuser **3200**, except that rather than varying the stagger angle of first vanes **3302**, the stagger angle of one or more second vanes **3304** and associated channel divergence angles of adjacent passages **3306** may be varied. In some examples, the stagger angle of less than all of second vanes **3304** may be varied, resulting in diffuser **3300** having one or more aperiodic sections having one or more biased passages. In other examples, any one or more of the vane characteristic variations illustrated in FIGS. **22-33** may be combined in any combination.

FIG. **34** is an isometric view of a turbomachine **3400**, including impeller **3402** and vaneless diffuser **3404**. Diffuser **3404** extends between shroud **3406** and hub **3407**. Shroud **3406** extends from an impeller inlet **3408**, across an impeller exit/diffuser inlet **3410** to diffuser outlet **3412**. FIGS. **35** and **36** are additional views of shroud **3406** and hub **3407**. As shown in FIGS. **35** and **36**, exemplary shroud **3406** includes a plurality of flowwise grooves **3502** (only one labeled) that extend in a flowwise direction from a location upstream of diffuser inlet and adjacent impeller **3402**, to a location downstream of the diffuser inlet, in this example to diffuser outlet **3412** (FIG. **34**). Flowwise grooves **3502** are located in the surface of shroud **3406** and have rounded edges **3504**, giving the shroud wall a circumferential profile that approximates a periodic waveform. Exemplary grooves **3502** may be designed and configured to guide a portion of fluid flow in impeller **3402** into diffuser **3404** at a preferred angle, thereby increasing the performance of turbomachine **3400**. FIGS. **37-39** show turbomachine **3700**, which is substantially the same as turbomachine **3400** with equivalent components having the same name and same reference numeral suffix. Unlike turbomachine **3400**, turbomachine **3700** has flowwise grooves **3802** that are more closely spaced than flowwise grooves **3502** (FIG. **35**), with edges **3804** of adjacent grooves **3802** substantially touching at a leading edge region of the grooves.

FIGS. **40-42** show an exemplary turbomachine **4000**, which has the same impeller **3402** and shroud **3406** as turbomachine **3400** (FIGS. **34-36**), but an alternative hub **4002**, that, as can be best seen in FIG. **42**, also has flowwise grooves that extend in a flowwise direction, in this example, from diffuser inlet **4204** to diffuser outlet **4206**. In the example shown, diffuser **4004** has the same number of grooves **4202** as grooves **3502** in shroud **3406**, and similarly has grooves with rounded edges **4208**. Grooves **4202** are circumferentially aligned with grooves **3502**. As with grooves **3502**, hub-side grooves **4202** may be designed and configured to guide a portion of working fluid in a preferred direction to improve the performance of diffuser **4004**. FIGS. **43** and **44** show an alternate configuration from FIGS. **40-42**, wherein a circumferential location of hub-side grooves **4202** are clocked with respect to shroud-side grooves **3502**. In this example, each of hub-side grooves **4202** are aligned with a midpoint between adjacent shroud-side grooves **3502**. In other examples, any other relative circumferential positioning may be used.

FIGS. **45** and **46** show an exemplary shroud **4502** and hub **4504**, each having flowwise grooves **4506** and **4508**, respectively. Unlike the embodiments shown in FIGS. **40-44**, shroud **4502** and hub **4504** also include biased passages **4510**, **4512**, in the form of enlarged flowwise grooves that have a larger cross-sectional area than grooves **4506**, **4508**. Such biased passages may be located, configured, and dimensioned to bias a circumferential pressure distribution toward circumferential uniformity, and/or provide other performance enhancements described herein. In other examples, one or both of shroud **4502** and hub **4504** may have additional biased flowwise grooves, or one or more biased flowwise grooves may be located in only the shroud or hub. The examples shown in FIGS. **45** and **46** include a periodic portion of passageways in the form of flowwise grooves and an aperiodic portion, in the illustrated example, having one biased passageway.

FIG. **47** is a cross-sectional elevation view of a biased diffuser passage **4702** disposed between passages **4704**. Biased passage **4702** has an increased passage height H**1** from recesses **4706** located in shroud **4708** and recess **4710** located in shroud **4712**. Recesses **4706** and **4710** may be similar in shape and location to grooves **3502** (FIG. **35**), **4202** (FIG. **42**), or may have other configurations, e.g., different leading and/or trailing edge location, width, flowwise length, etc. For example, in some embodiments, recesses **4706** and **4710** may have a leading edge located at a diffuser inlet. In the example shown in FIG. **47**, only one recess **4706**, **4710** is located in the hub and shroud **4708**, **4712**, thereby creating an aperiodic portion having a biased passage with a larger cross-sectional area than other passages in diffuser **4700**. In other examples a plurality of diffuser passages may have an increased height from one or more recesses located in the hub and/or shroud.

FIG. **48** is an isometric view of a turbomachine **4800**, including impeller **4802** and vaneless diffuser **4804**. Diffuser **4804** extends between shroud **4806** and hub **4807**. Shroud **4806** extends from an impeller inlet **4808**, across an impeller exit/diffuser inlet **4810** to diffuser outlet **4812**. FIG. **49** is an additional view of shroud **4806** and hub **4807**. As shown in FIGS. **48** and **49**, exemplary shroud **4806** and hub **4807** each include a plurality of flowwise channels **4820**, **4822**, respectively (only one of each labeled) that extend in a flowwise direction. Channels **4820**, **4822** as well as flowwise grooves **3502** (FIG. **35**), **3802** (FIG. **38**), and **4202** (FIG. **42**) are all flowwise elongate recesses. Channels **4820** and **4822** differ from grooves **3502**, **3802**, **4202**, by the cross-sectional shape of the recess, with the channels having a substantially square edge **4902** (FIG. **49**) and the grooves having a rounded edge **3504** (FIG. **35**). Shroud surface channels **4820** extend from a location upstream of diffuser inlet **4810** and adjacent impeller **4802**, to a location downstream of the diffuser inlet, in this example to diffuser outlet **4812**. Hub surface channels **4822** extend across the entire length of hub **4807** from diffuser inlet **4810** to diffuser outlet **4812**. Flowwise channels **4820** are located in the surface of shroud **4806** and have substantially square edges **4902** giving the shroud wall a circumferential profile that approximates a periodic square waveform. Similarly, flowwise channels **4822** are located in the surface of hub **4807** and have substantially square edges **4904** giving the hub wall a circumferential profile that approximates a periodic square waveform. Exemplary channels **4820** and **4822** may be designed and configured to guide a portion of fluid flow in impeller **4802** into diffuser **4804** at a preferred angle, thereby increasing the performance of turbomachine **4800**. In other embodiments, the characteristics of one or both of channels **4820**, **4822** may be varied, such as a depth, width, and number of channels. In the example shown in FIGS. **48** and **49**, channels **4820** and **4822** are circumferentially aligned, however, in other examples, the relative positions may be clocked such that the hub and shroud channels are not aligned.

FIGS. **50** and **51** show an alternative diffuser **5000** that is similar to diffuser **4804** (FIG. **48**) and includes hub **5002** and shroud **5004** having hub flowwise channels **5006** and shroud flowwise channels **5008**. Unlike diffuser **4804**, one of each of channels **5006** and **5008** have a characteristic that is different than the other channels **5006**, **5008**, here, a channel **5006***a* and **5008***a* each having an enlarged depth, resulting in a biased passage. In other examples, a characteristic of just hub channels **5006** or just shroud channels **5008** may be varied from other ones of the hub and shroud channels to create a biased passage. In some examples, characteristics other than depth may be varied, such as cross-sectional shape (e.g., groove versus channel), width, length, leading edge location, and trailing edge location). In some examples, more than one of hub and/or shroud channels **5006**, **5008** may be varied to create a larger aperiodic section having more than one biased passage, or more than one aperiodic section. In yet other examples, diffusers made in accordance with the present disclosure may have a smaller number of flowwise recesses located at select circumferential locations, rather than a plurality of flowwise recesses equally spaced around the entire circumference of the machine. For example, diffusers made in accordance with the present disclosure may have only one, two, three, etc. flowwise recesses located in select locations around the circumference of the machine.

FIGS. **52** and **53** show an exemplary vaned diffuser **5200** having a shroud **5202** and hub **5204**, the shroud extending from an impeller inlet **5206**, across a diffuser inlet **5208** to a diffuser exit **5210**. Shroud **5202** includes flowwise channels **5212** extending to locations upstream and downstream of diffuser inlet **5208** and are separated by upper legs **5214** of a leading edge **5216** of vanes **5218**. In the illustrated example, leading edges **5216** have a scalloped, also referred to herein as a swallowtail shape. In the illustrated example, hub **5204** does not include any flowwise recesses. In other examples, hub **5204** may include flowwise recesses, such as channels or grooves.

As shown in FIGS. **52** and **53**, a biased channel **5212***a* has a different characteristic than the other channels **5212**, here, a leading edge location **5220** that is farther upstream than a leading edge location **5222** of channels **5212** (best seen in FIG. **52**) and a depth that is greater than a depth of channels **5212** (best seen in FIG. **53**). Biased channel **5212***a* creates a biased passage in a aperiodic section of diffuser **5200**.

The foregoing has been a detailed description of illustrative embodiments of the invention. It is noted that in the present specification and claims appended hereto, conjunctive language such as is used in the phrases "at least one of X, Y and Z" and "one or more of X, Y, and Z," unless specifically stated or indicated otherwise, shall be taken to mean that each item in the conjunctive list can be present in any number exclusive of every other item in the list or in any number in combination with any or all other item(s) in the conjunctive list, each of which may also be present in any number. Applying this general rule, the conjunctive phrases in the foregoing examples in which the conjunctive list consists of X, Y, and Z shall each encompass: one or more of X; one or more of Y; one or more of Z; one or more of X and one or more of Y; one or more of Y and one or more of Z; one or more of X and one or more of Z; and one or more of X, one or more of Y and one or more of Z.

Various modifications and additions can be made without departing from the spirit and scope of this invention. Features of each of the various embodiments described above may be combined with features of other described embodiments as appropriate in order to provide a multiplicity of feature combinations in associated new embodiments. Furthermore, while the foregoing describes a number of separate embodiments, what has been described herein is merely illustrative of the application of the principles of the present invention. Additionally, although particular methods herein may be illustrated and/or described as being performed in a specific order, the ordering is highly variable within ordinary skill to achieve aspects of the present disclosure. Accordingly, this description is meant to be taken only by way of example, and not to otherwise limit the scope of this invention.

Further alternative exemplary embodiments of the present invention are described in the paragraphs below.

In one example, a diffuser for a turbomachine includes a plurality of diffuser passages located around a circumference of the diffuser for receiving a flow field having a circumferential pressure distribution; the diffuser passages include at least one periodic section and at least one aperiodic section, the at least one aperiodic section including at least one biased passage that is located, configured, and dimensioned to bias the circumferential pressure distribution toward circumferential uniformity. Such an exemplary embodiment may also include one or more of the following features:

- The plurality of diffuser passages have a first spatial frequency, the circumferential pressure distribution including a time averaged low frequency component that has a lower spatial frequency than the first spatial frequency, the at least one biased passage configured to bias the low frequency component toward a circumferentially uniform pressure distribution.
- The at least one periodic section includes a plurality of first vanes and the at least one biased passage includes at least one second vane, the first and second vanes each having a plurality of vane characteristics including one or more of a leading edge located at a leading edge location, a trailing edge located at a trailing edge location, a radial distance from a diffuser centerline, a chord length, a maximum thickness, a height, a flowwise shape distribution, a stagger angle, vane pitch, vane wedge angle, vane lean, vane twist, vane leading edge shape, and channel divergence angle, at least one of the plurality of vane characteristics of the at least one second vane is different from at least one of the plurality of vane characteristics of the plurality of first vanes.
- The at least one of the plurality of second vane characteristics that are different from the first vane characteristics include differences in any of the plurality of vane characteristics in any combination.
- The leading edge of the at least one second vane is located at a different radial distance from the diffuser centerline than the leading edges of the plurality of first vanes.
- The trailing edge of the at least one second vane is located at a different radial distance from the diffuser centerline than the trailing edges of the plurality of first vanes.
- The at least one second vane is located at a different radial distance from the diffuser centerline than the first vanes.
- The second vane chord length is different than the first vane chord length.
- The second vane maximum thickness is different than the first vane maximum thickness.
- The second vane height is different than the first vane height.
- The diffuser includes hub and shroud surfaces, the plurality of diffuser passages extending between the hub and shroud surfaces, the second vane is a partial height vane affixed to either the hub or shroud surface.
- The second vane flowwise shape distribution is different than the first vane flowwise shape distribution.
- The second vane stagger angle is different than the first vane stagger angle.
- The at least one biased passage is blocked.
- The stagger angle of the at least one second vane is fixed.
- The stagger angle of the at least one second vane is adjustable.
- The second vane pitch is different than the first vane pitch.
- The plurality of diffuser passages each have a passage height, the passage height of the at least one biased passage being different than the passage height of the diffuser passages in the periodic section.
- The diffuser includes a hub surface, a shroud surface, and a flowwise recess located in at least one of the hub and shroud surfaces, the flowwise recess extending upstream of and aligned with the at least one biased passage.
- The diffuser includes a hub surface, a shroud surface, and at least one elongate flowwise recess located in at least one of the hub and shroud surfaces.
- The diffuser includes a plurality of elongate flowwise recesses, the plurality of elongate flowwise recesses having an aperiodic arrangement around the circumference of the diffuser.
- The circumferential pressure distribution does not originate from an asymmetric flow path located upstream or downstream of the diffuser.
- The circumferential pressure distribution does not originate from an asymmetric flow path located upstream or downstream of the diffuser, the asymmetric flow path selected from the group consisting of a side inlet, an asymmetric collector, and a volute.
- The at least one biased passage is not located in a volute distortion zone proximate a volute tongue or proximate a location 180 degrees from the volute distortion zone.
- The diffuser is configured for use in a centrifugal compressor or pump, the at least one biased passage is configured and dimensioned to limit or reduce a variation in a magnitude of the circumferential pressure distribution so as to improve a stage efficiency by more than 0.2 percentage points, to cause a more uniform impeller exit flow distribution, to improve a maximum through-flow at a given speed by more than 0.1%, to reduce a surge line by more than 0.2%, or to reduce vibratory stress levels on an impeller or diffuser vanes by more than 0.2%.
- The diffuser is configured for use in a centrifugal compressor or pump, the periodic section having a spatial frequency and the circumferential pressure distribution having a primary spatial frequency that is less than the spatial frequency of the periodic section, the at least one biased passage is configured and dimensioned to reduce a maximum variation in a magnitude of the circumferential pressure distribution over a design operating range of the compressor or pump by more than 1%.
- The diffuser is configured for use in a centrifugal compressor or pump having an impeller configured to generate a pressure rise, the periodic section having a spatial frequency and the circumferential pressure distribution having a primary spatial frequency that is less than the spatial frequency of the periodic section, the at least one biased passage is configured and dimensioned to limit a maximum variation in a magnitude of the circumferential pressure distribution over a design operating range of the compressor or pump to less than 30% of an impeller pressure rise.
- The first and second vanes are located in the same row.

In another example, a diffuser including a plurality of first vanes arranged in a row around a portion of a circumference of the diffuser, each of the first vanes spaced a first circumferential distance from an adjacent first vane; and at least one second vane located between ones of the first vanes, the at least one second vane having a different characteristic than the first vanes, the different characteristic resulting in a biased passage proximate the at least one second vane for biasing a circumferential pressure distribution of a flow field entering the diffuser toward a circumferentially uniform pressure distribution. Such an exemplary embodiment may also include one or more of the following features:

- The different characteristic is selected from the group consisting of a radial distance of a leading or trailing edge from a diffuser centerline, a radial distance from a diffuser centerline, a chord length, a maximum thickness, a height, a flowwise shape distribution, a stagger angle, vane pitch, vane wedge angle, vane lean, vane twist, vane leading edge shape, and channel divergence angle.
- The plurality of first vanes have a spatial frequency, the biased diffuser passage being configured to bias a time averaged circumferential pressure distribution having a low frequency component that has a lower spatial frequency than the first vane spatial frequency, the biased passage configured to bias the low frequency component toward a circumferentially uniform pressure distribution.

In another example, a diffuser includes a hub and a shroud; a plurality of first vanes extending from the hub to the shroud and arranged in a row around a portion of a circumference of the diffuser; and at least one second vane located between ones of the first vanes, the at least one second vane extending from the hub to the shroud and having a different characteristic than the first vanes. Such an exemplary embodiment may also include one or more of the following features:

- The different characteristic is selected from the group consisting of a radial distance of a leading or trailing edge from a diffuser centerline, a radial distance from a diffuser centerline, a chord length, a maximum thickness, a height, a flowwise shape distribution, a stagger angle, vane pitch, vane wedge angle, vane lean, vane twist, vane leading edge shape, and channel divergence angle.

In yet another example, a diffuser includes a hub and a shroud; and a plurality of vane groupings each including at least two vanes, each of the at least two vanes having a different characteristic than other ones of the at least two vanes. Such an exemplary embodiment may also include one or more of the following features:

- The diffuser has a circumference, the vane groupings located around the circumference of the diffuser in a periodic arrangement.
- The at least two vanes are partial-height vanes, one of the at least two vanes affixed to the shroud and a second one of the at least two vanes affixed to the hub.
- A height of the at least two vanes are not the same.

In still another example, a method of designing a diffuser having an inlet and a plurality of vanes to reduce a circumferential pressure variation proximate the inlet, the pressure variation having a primary spatial frequency that is less than a spatial frequency of the vanes. The method includes providing a plurality of diffuser passages each having an inlet and located around a circumference of the diffuser; and locating at least one biased diffuser passage between ones of the plurality of diffuser passages, the biased diffuser passage having a different cross-sectional area than the plurality of diffuser passages for minimizing the circumferential pressure variation at the inlets of the plurality of diffuser passages.

In another example, a method of designing a diffuser including developing a computational model of an axisymmetric diffuser; calculating a performance of the diffuser when a circumferential pressure distribution having a time averaged low-frequency circumferential variation is present at an inlet to the diffuser; modifying the computational model to add at least one biased flow passage to the diffuser; calculating a performance of the modified diffuser; and comparing the diffuser performance from the two calculating steps to determine if the biased flow passage improved diffuser performance.

In a further example, a method of designing a diffuser including measuring a circumferential pressure distribution at an inlet to a first diffuser having periodic diffuser passages; replacing the first diffuser with a second diffuser having at least one aperiodic section with at least one biased diffuser passage; measuring a circumferential pressure distribution at an inlet to the second diffuser; and comparing the pressure distributions from the two measuring steps to determine whether the second diffuser reduced an undesired variation in a magnitude of the measured circumferential pressure distribution by a predetermined amount. Such an exemplary embodiment may also include one or more of the following features:

- calculating a performance of the first diffuser;
- calculating a performance of the second diffuser; and
- comparing the performance from the two calculating steps to determine whether the second diffuser improved diffuser performance by a predetermined amount.

In another example, a vaneless diffuser including an inlet and an exit; a hub surface and a shroud surface each extending between the inlet and the exit; and a plurality of flowwise recesses in at least one of the hub and shroud surfaces, the plurality of recess being aperiodic. Such an exemplary embodiment may also include one or more of the following features:

- The plurality of flowwise recesses include one or more first flowwise recesses and one or more second flowwise recesses, the one or more second flowwise recesses having at least one characteristic that is different than the first flowwise recesses.
- The at least one characteristic that is different is selected from the group consisting of a length, width, leading edge location, trailing edge location, depth, and cross-sectional shape.

In another example, a diffuser for a turbomachine, including a plurality of diffuser passages located around a circumference of the diffuser for receiving a flow field, the flow field has a circumferential pressure distribution; the diffuser passages include a first set of passages each having a first effective cross-sectional area distribution along a flow-wise direction and at least one biased passage having a second effective cross-sectional area distribution along the flowwise direction, the first and second effective cross-sectional area distributions being different, the at least one biased passage located, configured, and dimensioned to bias the circumferential pressure distribution toward circumferential uniformity.

Exemplary embodiments have been disclosed above and illustrated in the accompanying drawings. It will be understood by those skilled in the art that various changes, omissions and additions may be made to that which is specifically disclosed herein without departing from the spirit and scope of the present invention.

What is claimed is:

1. A diffuser, comprising:

an inlet, a hub, and a shroud; and

a row of vanes including a plurality of vane groupings each including a plurality of first partial height vanes affixed to one of the hub and the shroud, and a plurality second partial height vanes circumferentially spaced from the first partial height vane and affixed to the other of the hub and the shroud;

wherein adjacent ones of the first and second partial height vanes overlap in a spanwise direction when viewed from a direction perpendicular to the spanwise direction, the spanwise direction being a direction extending between the hub and the shroud;

wherein the first partial height vanes are affixed to the hub, wherein at least one of the first partial height vanes is upstream of the remaining first partial height vanes, and wherein a height of the at least one of the first partial height vanes is greater than or equal to a height of the remaining partial height vanes.

2. The diffuser of claim **1**, wherein a height of one or more of the first partial height vanes or one or more of the second partial height vanes is between 5% and 65% of the passage height.

3. A diffuser, comprising:

an inlet, a hub, and a shroud; and

a row of vanes including a plurality of vane groupings each including a plurality of first partial height vanes affixed to one of the hub and the shroud, and a plurality second partial height vanes circumferentially spaced from the first partial height vane and affixed to the other of the hub and the shroud;

wherein adjacent ones of the first and second partial height vanes overlap in a spanwise direction when viewed from a direction perpendicular to the spanwise direction, the spanwise direction being a direction extending between the hub and the shroud;

wherein a height of at least one of the first partial height vanes or at least one of the second partial height vanes is between 5% and 65% of the passage height.

4. The diffuser of claim **3**, wherein at least some of the vanes in the row of vanes have differing stagger angles relative to one another.

5. The diffuser of claim **3**, wherein the overlap in the spanwise direction between adjacent ones of the first and second partial height vanes is greater than or equal to 10% of the passage height.

6. The diffuser of claim **3**, wherein the row of vanes includes at least one full height vane.

7. The diffuser of claim **3**, wherein each of the first and second partial height vanes has a leading edge, the leading edges of the first and second partial height vanes being aligned in a flowwise direction.

8. The diffuser of claim **3**, wherein the diffuser has an inlet, and at least one of the first and second partial height vanes is located at the inlet.

9. The diffuser of claim **3**, wherein the first partial height vanes are affixed to the hub, wherein one or more of the first partial height vanes is upstream of the remaining first partial height vanes, and wherein a height of the one or more of the first partial height vanes is greater than or equal to a height of the remaining partial height vanes.

10. The diffuser of claim **3**, wherein the plurality of first partial height vanes are the only partial height vanes affixed to the hub, and the first partial height vanes have leading edges that are aligned in the flowwise direction.

11. The diffuser of claim **3**, wherein the height of the at least one of the first partial height vanes or the at least one of the second partial height vanes is between 5% and 15% of the passage height.

12. The diffuser of claim **3**, wherein the row of vanes define a plurality of passages each having a height extending in the spanwise direction between the hub and the shroud and extending in a circumferential direction between adjacent ones of the first and second partial height vanes, the plurality of passages including at least one biased passage, a spanwise height of the at least one biased passage being greater than a spanwise height of other ones of the plurality of passages.

13. The diffuser of claim **3**, wherein the first and second partial height vanes are positioned in an alternating and repeating spatial arrangement.

14. The diffuser of claim **3**, wherein the diffuser is a single row diffuser, the row of vanes being the only row of vanes in the diffuser.

15. The diffuser of claim **3**, wherein the hub includes a hub surface and the shroud includes a shroud surface, the diffuser further including at least one elongate flowwise recess located in at least one of the hub and shroud surfaces.

16. The diffuser of claim **15**, wherein the at least one elongate flowwise recess includes a plurality of elongate flowwise recesses having an aperiodic arrangement around a circumference of the diffuser.

17. The diffuser of claim **3**, wherein the plurality of first and second partial height vanes are stationary and have a fixed spacing between adjacent ones of the first and second partial height vanes.

18. The diffuser of claim **3**, wherein the row of vanes is a first row of vanes located downstream of an inlet of the diffuser.

19. The diffuser of claim **3**, wherein the row of vanes includes at least one aperiodic section, the at least one aperiodic section including at least one biased passage defined by at least one vane having a different characteristic than the first and second partial height vanes.

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